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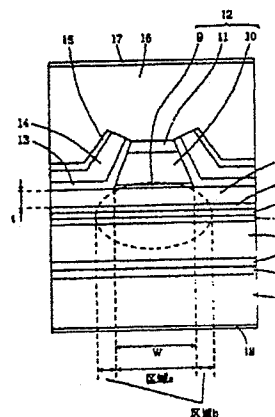
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[54]发明名称 半导体激光器件及其设计方法

[57]摘要

一种半导体激光器件包括第一导电型敷层、有源层、第二导电型敷层和电流阻挡层。设定有效折射率之差值 Δn 和开口宽度 $W[\mu m]$ ，使之满足一预定关系。通过选择电流阻挡层的 Al 的组分比和开口两侧第二导电型敷层的厚度，可设定实折射率之差值 Δn 。



说明书

半导体激光器件及其设计方法

5 本发明涉及一种半导体激光器件及其设计方法。

近年来，一直在积极地研究开发能工作于小工作电流的半导体激光器件。IEEE JOURNAL OF SELECTED TOPICS IN QUANTUM ELECTRONICS, VOL. 1, NO. 1, PP. 102 - 109, 1995 曾报导过一种应用透明电流阻挡层的有效折射率导向型(real refractive index guided) 半导体
10 激光器，可以减小其工作电流。

在这种有效折射率导向型半导体激光器件中，认为当有效折射率差值大到某种程度时，横向模是稳定的。例如在上述资料中，有效折射率差值约为 5×10^{-3} 。

然而，在上述应用透明电流阻挡层的有效折射率导向型半导体激光
15 器件中，难以以基本的横向模激光产生更大的光输出功率。

再者，在上述的实折射导向型半导体激光器件中，可以减小腔内损耗，故能得到很大的光输出功率。然而，当把该半导体激光器件应用于光头作为可重写光盘诸如磁光盘或相变盘的光源时，就要求半导体激光器件实现更大的光输出功率。此外，在高于四倍速度作写操作时，相对
20 于激光器件的输出功率，希望以基本横向模激光产生的最大光输出功率不小于 70mw，而沿水平方向的水平光束发散角 θ_H 不小于 6.5° ，以便在光头携带半导体器件的情况下减小噪声特性等。

本发明的一个目的是提供一种能以基本的横向模激光获得大的光输出功率的半导体激光器件及其设计方法。

25 本发明的另一个目的是提供一种能以基本的横向模激光提高最大光输出功率并增大沿水平方向的水平光束发散角 θ_H 的半导体激光器件及其设计方法。

根据本发明的半导体激光器件包括第一导电型包层、有源层、第二导电型敷层和电流阻挡层，电流阻挡层具有预定宽度的条形开口用来限定电流路径并形成该电流路径，且其带隙大于第二导电型敷层的带隙，
30 其折射率依次小于第二导电型敷层的折射率，第二导电型敷层有一平坦部分且在其上有一条状脊形部分(ridge portion)，该脊形部分定位于电流

阻挡层的开口内，如此形成电流阻挡层以覆盖住平坦部分的上表面和脊形部分的侧表面，而且，激有源层中对应于开口的区域（即发光区中面向开口的区域或/和发光区中包括开口的区域）的有效折射率与有源层中对应于开口两侧的区域（即发光区中面向开口两侧的区域或/和发光区中包括开口两侧的区域）的有效折射率之间的差值 Δn 以及这宽度 $W[\mu m]$ 满足下述关系：

$$\Delta n \geq 2 \times 10^{-3},$$

$$W \leq -1.6 \times 10^{-3} \times \Delta n + 9.3, \quad \text{以及}$$

$$W \geq 3.0$$

10 这样，就提供了一种所谓的脊形波导型(ridge wave guided)半导体激光器件。离开有源层某一距离的脊形部分的宽度可以随该距离的增大而减小。

在该半导体激光器件中，能以小的工作电流以和基本横向模激光获得大的光输出功率。例如，可获得不小于 100mw 的光输出功率。

15 由于有效折射率之间的差值 Δn 不小 2×10^{-3} ，因此可保持一种良好的有效折射率导向型结构。因开口宽度 W 不小于 $3.0\mu m$ ，故有高可靠性。

有效折射率之间的差值 Δn 与开口宽度 W 满足下述关系则更好。

$$W \leq -1.5 \times 10^{-3} \times \Delta n + 8.55$$

20 这样，就能以基本横向模激光得到不小于 150mw 的光输出功率。

第一导电型敷层可以是 $Al_xGa_{1-x}As$ ，有源层可以是 $Al_qGa_{1-q}As$ ($1 > x > q \geq 0$)，第二导电型敷层可以是 $Al_yGa_{1-y}As$ ($y > q$)，而电流阻挡层可以是 $Al_zGa_{1-z}As$ 。

此时，能以小的工作电流和基本横向模激光得到大的光输出功率。

25 例如，能以基本横向模激光得到不小于 100mw 的光输出功率。

通过选择电流阻挡层的 Al 的组分比 z 和开口两侧第二导电型敷层的厚度，可以设定有效折射率之间的差值 Δn 。

第一导电型敷层的 Al 的组分比 x 和第二导电型敷层的 Al 的组分比 y ，最好是既不小于 0.4，又不大于 0.6。

30 电流阻挡层的 Al 的组分比 z 最好大于第二导电型敷层的 Al 的组分比 y 。若电流阻挡层的 Al 的组分比 z 与第二导电型敷层的 Al 的组分比 y 之差不小于 0.02，则更好。在这种情况下，就能容易地在有效折射率之间

实现很好的差值。

电流阻挡层的 Al 的组分比 z 最好不大于 0.6，这样就提高了电流阻挡层的结晶性，由此还提高了形成于电流阻挡层上的一层的结晶性，因而能提供高可靠性的半导体激光器件。

- 5 电流阻挡层最好至少包括一第一导电型层。这样，电流阻挡层中的第一导电型层与第二导电型层的导电类型相反，由此可实现充分的电流阻挡作用。电流阻挡层可以只用第一导电型层构成。

- 10 电流阻挡层可以包括形成于有源层上的第一层和形成于该第一层上的第二层，第二层可以是第一导电型，而第一层的杂质浓度可以比第二层的杂质浓度低。在这种情况下，可防止杂质从电流阻挡层扩散入有源层。特别是，第一层最好是一种非掺杂层。

若用第一导电层构成电流阻挡层，则离有源层某一距离的电流阻挡层的杂质浓度可以随距离的缩短而降低。

- 15 在第二导电型层中可以存在诸如阻止蚀刻层之类厚度不大于 300\AA 的另外一层，因为这几乎不影响有效折射率之间的差值。

此外，可以在电流阻挡层上设置一吸收激光光线的第一导电型电流阻挡层。

最好在第一导电型半导体衬底上形成第一导电型层。在 AlGaAs 系半导体激光器件中，最好使用 GaAs 衬底。

- 20 有源层可以拥有一种由单量子阱层构成的单量子阱结构，可以拥有一种由交替堆迭量子阱层与阻挡层构成的多量子阱结构，或者可以是一种无量子效应的单层结构。

- 25 AlGaAs 系半导体激光器件的多量子阱结构可以包括由 $\text{Al}_q\text{Ga}_{1-q}\text{As}$ ($1 > x > q \geq 0$, $1 > y > q \geq 0$) 构成的量子阱层和由 $\text{Al}_p\text{Ga}_{1-p}\text{As}$ ($x \geq p > q$, $y \geq p > q$) 构成的阻挡层。

半导体激光器件能以基本横向模激光获得不低于 100mw 光输出功率为较佳，而半导体激光器件能以基本横向模激光获得不低于 150mw 光输出功率则更佳。

- 30 根据本发明另一方面的半导体激光器件的设计方法是一种设计半导体激光器件的方法，该激光器件包括依次由 $\text{Al}_x\text{Ga}_{1-x}\text{As}$ 构成的第一导电型层、由 $\text{Al}_q\text{Ga}_{1-q}\text{As}$ ($1 > x > q \geq 0$) 构成的有源层、由 $\text{Al}_y\text{Ga}_{1-y}\text{As}$ ($y > q$) 构成的第二导电型层及电流阻挡层，该电流阻挡层有一预定宽度的条形

开口用来限制电流路径并形成该电流路径，并由 $\text{Al}_z\text{Ga}_{1-z}\text{As}$ ($1 \geq z > y$) 构成，它包括以下几个步骤：设定有源层中对应于开口的区域内有效折射率与有源层中对应于开口两侧区域内的有效折射率之间的差值 Δn 以及开口宽度 W ，以便以基本横向模激光获得预定的光输出功率；以及选择电
5 流阻挡层的 Al 的组分比 z 和开口两侧第二导电型敷层的厚度，以便得到有效折射率之间的差值 Δn 。

这样，所构成的半导体激光器件就以小的工作电流和基本横向模激光获取大的光输出功率。

设定步骤最好包括设定有效折射率之间的差值 Δn 以及开口宽度
10 $W[\mu\text{m}]$ 的步骤，以满足下述关系：

$$\Delta n \geq 2 \times 10^{-3}, \text{ 以及}$$

$$W \leq -1.6 \times 10^3 \times \Delta n + 9.3$$

这样，所构成的半导体激光器件就以基本横向模激光获取不小于
100mw 的光输出功率。

15 设定步骤更好的是包括设定有效折射率之间的差值 Δn 和开口宽度 $W[\mu\text{m}]$ 以满足下述关系的步骤：

$$W \leq -1.5 \times 10^3 \times \Delta n + 8.55$$

这样，所构成的半导体激光器件就以基本横向模激光获取不小于
150mw 的光输出功率。

20 设定步骤最好包括把开口宽度 W 设定不小于 $3.0\mu\text{m}$ 的步骤，这样就得到了高可靠性的半导体激光器件。

第二导电型敷层可以依次包括一平坦部分和在其上面的一条状脊形部分，脊形部分可以定位在电流阻挡层的开口内，而且如此形成电流阻挡层以覆盖住平坦部分的上表面和脊形部分的侧表面。这样，就提供了一
25 种所谓的脊形波导型半导体激光器件。离有源层某一距离的脊形部分的宽度可随距离的增大而减小。

根据本发明还有一方面的半导体激光器件，包括第一导电型敷层、有源层、第二导电型敷层和电流阻挡层，电流阻挡层具有一预定宽度的条形开口用以限制电流路径并形成该电流路径，且其带隙大于第二导电
30 型敷层的带隙，其折射率则小于第二导电型敷层的折射率，第二导电型敷层有一平坦部分和在其上面的一条状脊形部分，该脊形部分定位于电流阻挡层的开口内，如此形成电流阻挡层以覆盖住平坦部分的上表面和

脊形部分的侧表面，而且，有源层中对应于开口的区域的有效折射率与有源层中对应于开口两侧区域的有效折射率之差 Δn 以及开口宽度 $W[\mu m]$ 满足以下关系：

$$2.4 \times 10^{-3} \leq \Delta n \leq 3.5 \times 10^{-3},$$

5

$$W \geq 2.5,$$

$$W \leq -1.33 \times 10^3 \times \Delta n + 8.723, \text{ 以及}$$

$$W \leq 2.25 \times 10^3 \times \Delta n - 2.8$$

这样，就提供了一种所谓的脊形波导型半导体激光器件。在离有源层某一距离，脊形部分宽度可随距离增大而减小。

10

在根据本发明的半导体激光器件中，能以基本横向模激光获得大的最大光输出功率和大的水平光束发散角。例如，能以基本横向模激光把最大光输出功率增加到不小于 70mw，又如可把水平光束发散角增大到不小于 6.5° 。

使有效折射率之间的差值 Δn 与开口宽度 $W[\mu m]$ 满足下述关系则更好：

15

$$W \leq -1.33 \times 10^3 \times \Delta n + 7.923$$

这样，就以基本横向模激光获得不小于 100mw 的最大光输出功率。

更好的是这使有效折射率之间的差值 Δn 和开口宽度 $W[\mu m]$ 满足以下关系：

20

$$W \leq 2.25 \times 10^3 \times \Delta n - 3.175$$

这样，可把水平光束发散角增大到不小于 7° 。

第一导电型敷层可由 $Al_xGa_{1-x}As$ 构成，有源层可由 $Al_qGa_{1-q}As$ ($1 > x > q \geq 0$) 构成，第二导电型敷层可由 $Al_yGa_{1-y}As$ ($y > q$) 构成，而电流阻挡层可由 $Al_zGa_{1-z}As$ 构成。

25

这样，能以基本横向模激光获得不小 70mw 的最大光输出功率，且水平光束发散角可不小于 6.5° 。

可以通过选择电流阻挡层的 Al 的组分比 z 和开口两侧第二导电型敷层的厚度来设定有效折射率之间的差值 Δn 。

第一导电型敷层的 Al 的组分比 x 和第二导电型敷层的 Al 的组合比 y ，最好既不小于 0.4 也不大于 0.6。

30

使电流阻挡层的 Al 的组分比 z 大于第二导电型敷层的 Al 的组分比 y 则较佳。更好的是使电流阻挡层的 Al 的组分比 z 与第二导电型敷层的 Al

的组分比 y 之差值不小于 0.02。这样，能容易实现有效折射率之间的良好差值。

5 电流阻挡层的 Al 的组分比 z 最好不大于 0.6,这样就提高了电流阻挡层的结晶性，由此也提高了电流阻挡层上形成的层的结晶性，因而能提供高可靠性的半导体激光器件。

电流阻挡层最好至少包括一第一导电型层，这样，电流阻挡层中的第一导电型层与第二导电型层的导电类型相反，据此能实现充分的电流阻挡作用。可以只用第一导电型层构成电流阻挡层。

10 电流阻挡层可以包括形成于有源层上的第一层和形成于第一层上的第二层，第二层可以是第一导电型层，而第一层的杂质浓度可以低于第二层的杂质浓度。这样，可防止杂质从电流阻挡层扩散入有源层。特别是，第一层最好是非掺杂层。

若电流阻挡层是用第一导电型层构成的，则在离有源层某一距离处，电流阻挡层的杂质浓度可随距离的减小而减小。

15 在第二导电型层内可以存在其厚度不大于 300\AA 的诸如蚀刻阻止层之类的另外一层，因为这几乎不影响有效折射率之间的差值。

再者，可在电流阻挡层上设置吸收激光光线的第一导电型电流阻挡层。

20 最好在第一导电型半导体衬底上形成第一导电型层。在 AlGaAs 系半导体激光器件中，最好使用 GaAs 衬底。

有源层可以具有一种由单量子阱层构成的单量子阱结构，可以具有一种通过交替堆迭量子阱层与阻挡层构成的多量子阱结构，或可以是无量子效应的单层结构。

25 AlGaAs 系半导体激光器件的多量子阱结构可以包括由 $\text{Al}_q\text{Ga}_{1-q}\text{As}$ ($1 > x > q \geq 0$, $1 > y > q \geq 0$)组成的量子阱层和由 $\text{Al}_p\text{Ga}_{1-p}\text{As}$ ($x \geq p > q0$, $y \geq p > q$)组成的阻挡层。

30 较好的是，半导体激光器件以基本横向模激光获取不小于 70mw 的最大光输出功率。更好的是，半导体激光器件以基本横向模激光获取不小于 100mw 的最大光输出功率。另一方面，较好的是，半导体激光器件获得不小于 6.5° 的水平光束发散角。更好的是，半导体激光器件获得不小于 7° 的水平光束发散角。

由于光束近似为一个整圆，所以有利于光头中的光学设定工作。由

于垂直光束发散角大于水平光束发散角，譬如大约 $15 - 30^\circ$ ，所以水平光束发散角可以大到像垂直光束发散角那样的程度。

此外，随着腔体长度的缩短，可把水平光束发散角做得稍大些。另一方面，如果腔体长度小于约 $300\mu\text{m}$ ，则 COD(突然光学损坏)的大小就会降低。因此，腔体长度最好保持在既不小于 $300\mu\text{m}$ 又不大于 $600\mu\text{m}$ 的范围内。

根据本发明又一方面的半导体激光器件设计方法是一种设计半导体激光器件的方法，该激光器件依次包括由 $\text{Al}_x\text{Ga}_{1-x}\text{As}$ 构成的第一导电型敷层、由 $\text{Al}_q\text{Ga}_{1-q}\text{As}$ ($1 > x > q \geq 0$) 构成的有源层、由 $\text{Al}_y\text{Ga}_{1-y}\text{As}$ ($y > q$) 构成的第二导电型敷层以及电流阻挡层，该电流阻挡层有一预定宽度的条形开口用来限制电流路径并形成该电流路径，并由 $\text{Al}_z\text{Ga}_{1-z}\text{As}$ ($1 \geq z > y$) 组成，它包括以下步骤：设定有源层中对应于开口的区域的有效折射率与有源层中对应于开口两侧区域的有效折射率之差值 Δn 以及开口宽度 W ，以便以基本横向模激光获取预定的最大光输出功率和预定的水平光束发散角；以及选择电流阻挡层的 Al 的组分比 z 和开口两侧第二导电型敷层的厚度，以得到有效折射率之间的差值 Δn 。

这样，就获得了一种以基本横向模激光取得大的最大光输出功率和大的水平光束发散角的半导体激光器件。

设定步骤最好包括设定有效折射率之差值 Δn 和开口宽度 $W[\mu\text{m}]$ 的步骤，以满足下述关系：

$$2.4 \times 10^{-3} \leq \Delta n \leq 3.5 \times 10^{-3},$$

$$W \geq 2.5,$$

$$W \leq -1.33 \times 10^3 \times \Delta n + 8.723, \text{ 以及}$$

$$W \leq 2.25 \times 10^3 \times \Delta n - 2.8$$

这样，就获得一种以基本横向模激光得到不小于 70mw 的最大光输出功率和不小于 6.5° 水平光束发散角的半导体激光器件。

设定步骤更好包括设定有效折射率之差值 Δn 开口宽度 $W[\mu\text{m}]$ 的步骤，以便满足下述关系：

$$W \leq -1.33 \times 10^3 \times \Delta n + 7.923$$

这样，就获得一种以基本横向模激光得到不小于 100mw 最大光输出功率的半导体激光器件。

设定步骤最好包括设定有效折射率之差值 Δn 和开口宽度 $W[\mu\text{m}]$ 的

步骤, 以便满足以下关系:

$$W \leq 2.25 \times 10^3 \times \Delta n - 3.175$$

这样, 就获得一种水平光束发散角不小于 7° 的半导体激光器件。

第二导电型敷层可包括一平坦部分和在其上面的条状脊形部分。脊形部分可定位于电流阻挡层的开口内, 而且如此形成电流阻挡层以覆盖住平坦部分的上表面和脊形部分的侧表面。这样, 就可提供一种所谓的脊波导型半导体激光器件。在离有源层某一距离处, 脊形部分宽度可随距离的增大而减小。

通过下面结合附图对本发明所作的详细介绍, 本发明的上述目的和其它目的、特征、方面和优点就更清楚了。

图 1 是根据本发明第一实施例的半导体激光器件的剖面示意图;

图 2 是表示有效折射率差值 Δn 与图 1 所示半导体激光器件中可实现基本横向模激光时获得的最大光输出功率 P_k 之间的关系曲线;

图 3 示出在图所示半导体激光器件中, 有效折射率差值 Δn 、可实现基本横向模激光时获得的最大光输出功率 P_k 以及条宽 W 之间的关系曲线;

图 4 是根据本发明第二实施例的半导体激光器件的剖面示意图;

图 5 表示图 4 所示半导体激光器件中有源层的示意的能带结构及附近状况的图;

图 6 表示图 4 所示半导体激光器件中, 有效折射率差值 Δn 、可实现基本横向模激光时获得的最大光输出功率 P_k 、条宽 W 及水平光束发散角 θ_H 之间的关系曲线;

图 7 表示图 4 所示半导体激光器件中条宽 W 与 COD (突然光学损坏) 之间的关系曲线; 以及

图 8 表示图 4 所示半导体激光器件中有效折射率差值 Δn 与像散性之间的关系曲线。

运用图 1 说明根据本发明第一实施例的一种 AlGaAs 系半导体激光器件。

在图 1 中, 在 (n 型 GaAs 衬底 1) 上依次形成 $0.5\mu\text{m}$ 厚 Se 掺杂 n 型 GaAs 缓冲层 2、 $0.1\mu\text{m}$ 厚 Se 掺杂 n 型 $\text{Al}_s\text{Ga}_{1-s}\text{As}$ 缓冲层 3 和 $2.3\mu\text{m}$ 厚 Se 掺杂 n 型 $\text{Al}_x\text{Ga}_{1-x}\text{As}$ 敷层 4, 其中 $x>s>0$ 。在本发明实施例中, $s=0.18$, $x=0.45$ 。

在 n 型敷层 4 上依次形成 410A 厚非掺杂 $\text{Al}_v\text{Ga}_{1-v}\text{As}$ 光波导层 5、100A 厚由 $\text{Al}_q\text{Ga}_{1-q}\text{As}$ 组成的具有单量子阱结构的非掺杂有源层 6 以及 410A 厚非掺杂 $\text{Al}_w\text{Ga}_{1-w}\text{As}$ 光波导层 7, 其中 $1 > x > v, v > q \geq 0, w > q \geq 0, y_1 > w, Y_2 > w$ 。在本发明实施例中, $v=0.35, q=0.035, w=0.35$ 。

5 在光波导层 7 上形成 $t\mu\text{m}$ 厚 Zn 掺杂 p 型 $\text{Al}_{y_1}\text{Ga}_{1-y_1}\text{As}$ 敷层 8。在本发明实施例中, $y_1=0.45$ 。

在 p 型敷层 8 的靠近中央部分上面, 依次形成沿垂直方向 (沿腔体长度方向) 延伸厚为 200A 的条形 Zn 掺杂 p 型 $\text{Al}_u\text{Ga}_{1-u}\text{As}$ 蚀刻阻止层 9、 $2\mu\text{m}$ 厚条形 Zn 掺杂 p 型 $\text{Al}_{y_2}\text{Ga}_{1-y_2}\text{As}$ 敷层 10 和 $0.4\mu\text{m}$ 厚条形 Zn 掺杂 p 型 GaAs 盖层 (cap layer) 11。p 型蚀刻阻止层 9 的宽度为 $W\mu\text{m}$, 宽度 $W\mu\text{m}$ 变为形成电流路径的开口宽度。这里, $1 \geq u > y_1, 1 \geq u > y_2$ 。在本发明实施例中, $u=0.7, y_2=0.45$ 。p 型蚀刻阻止层 9、p 型敷层 10 和 p 型盖层 11 构成了条状脊形部分 12。

在 p 型敷层 8 上面依次形成 $0.3\mu\text{m}$ 厚非掺杂 $\text{Al}_{z_1}\text{Ga}_{1-z_1}\text{As}$ 电流阻挡层 13、 $0.2\mu\text{m}$ 厚 Se 掺杂 n 型 $\text{Al}_{z_2}\text{Ga}_{1-z_2}\text{As}$ 电流阻挡层 14 和 $0.3\mu\text{m}$ 厚 Se 掺杂 n 型 GaAs 电流阻挡层 15, 使之覆盖住脊形部分 12 的侧表面, 其中 $1 \geq z_1 > y_1, 1 \geq z_1 > y_2, 1 \geq z_2 > y_1, 1 \geq z_2 > y_2$ 。

$6\mu\text{m}$ 厚 Zn 掺杂 p 型 GaAs 接触层 16 形成在 p 型盖层 11 的上表面、非掺杂电流阻挡层 13 的端面、n 型电流阻挡层 14 的端面以及 n 型电流阻挡层 15 的上表面与端面上。

在 p 型接触层 16 上形成由 Cr/Au 组成的 p 侧电极 17, 并在 n 型衬底 1 的下表面上形成由 Cr/Sn/Au 组成的 n 侧电极 18。

现在举例说明制造上述半导体激光器件的方法。

首先, 运用诸如金属有机化学气相沉积 (MOCVD) 法或分子束外延 (MBE) 法之类的气相外延 (VPE) 方法, 在 n 型 GaAs 衬底 1 上连续生长 n 型 GaAs 缓冲层 2、n 型 AlGaAs 缓冲层 3、n 型 AlGaAs 敷层 4、非掺杂 AlGaAs 光波导层 5、非掺杂有源层 6、非掺杂 AlGaAs 光波导层 7、p 型 AlGaAs 敷层 (平坦部分) 8、p 型 AlGaAs 或 AlAs 蚀刻阻止层 9、p 型敷层 (对应于以后形成的脊形部分) 10 以及 p 型 GaAs 盖层 11。p 型盖层 11 是保护层, 防止在制造过程中在 p 型敷层 10 上用暴露和氧化 p 型敷层 10 的办法作晶体生长的不可行性。

然后, 在 p 型 GaAs 盖层 11 上形成条形 SiO_2 膜, 并用 SiO_2 膜作为掩

模有选择地蚀刻掉 p 型蚀刻阻止层 9 下面的层, 之后, 用 SiO_2 膜作为掩模再蚀刻掉蚀刻阻止层 9 以形成脊形部分 12。由于蚀刻阻止层 9 的 Al 的组分比很大, 所以难以在蚀刻步骤之后在蚀刻阻止层 9 上生长出结晶性很好的晶体。因此, 在本发明实施例中去除了蚀刻阻止层 9。

5 接着, 运用上述的气相外延法在敷层 8 上依次连续生长电流阻挡层 13、14 和 15, 使之覆盖住脊形部分 12 的侧表面, 露出盖层 11 的上表面。此后, 运用上述的气相外延法在电流阻挡层 13、14 与 15 以及盖层 11 的上表面上生长 p 型 GaAs 接触层 16。

10 在半导体激光器件中, 具有条形开口 (条宽为 W) 以便限制电流路径并形成该电流路径的电流阻挡层 13 和 14 同 p 型敷层 8 和 10 相比, 其带隙更大而折射率较小。因此, 在发光区 (图 1 中用虚线椭圆示意地表示的区域) 中, 对应于开口的区域 a 内的有效折射率可以做得比对应于开口两侧的区域 b 内的有效折射率更大。所以半导体激光器件可以像有效折射率导向型半导体装置那样地工作。有效折射率差值表示在区域 a 15 检测到的具有激光波长的光的折射率与在区域 b 检测到的光的折射率之差。

运用上述结构, 电流阻挡层 13 和 14 就成了透明的电流阻挡层, 它对激光光线呈透明。

20 通过选择电流阻挡层 13 和 14 各自的 Al 的组分比 z_1 与 z_2 或者敷层 8 的厚度 t , 来改变半导体激光器件不工作时的有效折射率的差值 (对应于开口的区域 a 内的有效折射率减去对应于开口两侧的区域 b 内的有效折射率), 以测量基本横向模激光的最大光输出功率, 其结果示于图 2。在这种情况下, 在半导体激光器件的前后面分别配上反射率为 2 % 和 95 % 的反射膜, 腔体长度设定为 $1200\mu\text{m}$, 在 25°C 环境温度下进行测量。
25 表 1 列出了电流阻挡层 13 和 14 各自的 Al 的组分比 z_1 和 z_2 以及图 2 所示各点的 p 型敷层 8 的厚度 t 。编号 A1 - A5 的样品条宽为 $4.5\mu\text{m}$ 。

表 1

编 号	电流阻挡层 13 的 Al 的组分比 z_1	电流阻挡层 14 的 Al 的组分比 z_2	p 型敷层 8 的 厚度 $t(\mu\text{m})$
A1	0.53	0.53	0.25
A2	0.55	0.55	0.25

A3	0.59	0.59	0.25
A4	0.70	0.70	0.25
A5	0.70	0.70	0.25

图 2 表示当有效折射率差值不大于 3×10^{-3} 时可实现基本横向模激光所获得的最大光输出功率为不小于 100mw，当有效折射率差值不大于 2.6×10^{-3} 时为不小于 150mw，而当有效折射率差值不大于 2.3×10^{-3} 时为不小于 200mw。

另外，当有效折射率差值不大于 3×10^{-3} ，光输出功率为 100mw 的情况下，得到的激光阈值电流为 43mA，工作电流为 140mA，垂直光束发散角 18° ，水平光束发散角为 7° ；而当有效折射率差值不大于 2.5×10^{-3} ，光输出功率为 170mw 的情况下，得到的激光阈值电流为 45mA，工作电流为 185mA，垂直光束发散角为 18° ，水平光束发散角为 7° 。

当有效折射率差值不大于 2.3×10^{-3} 时，若光输出功率为 200mw，则得到的激光阈值电流为 47mA，工作电流为 235mA，垂直光束发散角为 18° ，水平光束发散角为 6.5° 。

这样，当有效折射率差值不大于 3×10^{-3} 时，就能以基本横向模激光在小的工作电流下得到大的光输出功率。

因此，在根据本发明实施例的半导体激光器件中，把有效折射率差值设定为不大于 3×10^{-3} ，且最好不大于 2.6×10^{-3} 。

通过选择电流阻挡层 13 和 14 各自的 A1 的组分比 z_1 和 z_2 、p 型敷层 8 的厚度 t 和条宽 W ，改变在半导体激光器件不工作时的有效折射率差值 Δn （对应于开口的区域 a 内的有效折射率减去对应于开口两侧区域的 b 内的有效折射率），以测量基本横向模激光的最大光输出功率 P_k ，其结果列于表 2。此时，在半导体激光器件的前后面分别配上射率为 2% 和 95% 的反射膜，腔体长度设定为 $1200\mu\text{m}$ ，在 25°C 环境温度下进行测量。样品 B4、B9、B14、B18 和 B21 分别对应于样品 A1、A2、A3、A4 和 A5。

表 2

编 号	Δn	$W(\mu m)$	$P_k(mW)$
B1	0.0023	5.5	110
B2	0.0023	5.1	150
B3	0.0023	4.7	180
B4	0.0023	4.5	200
B5	0.0025	6.0	90
B6	0.0025	5.4	95
B7	0.0025	5.0	120
B8	0.0025	4.8	150
B9	0.0025	4.5	170
B10	0.0025	4.2	200
B11	0.0030	5.7	80
B12	0.0030	5.3	85
B13	0.0030	4.9	90
B14	0.0030	4.5	100
B15	0.0030	4.3	120
B16	0.0038	5.3	55
B17	0.0038	4.9	60
B18	0.0038	4.5	60
B19	0.0050	5.5	45
B20	0.0050	4.9	45
B21	0.0050	4.5	50

5 图 3 表示利用表 2 内编号 B1 - B21 的样品获得的有效折射率差值 Δn 、可实现基本横向模激光时获得的最大光输出功率 P_k 以及条宽 W 之间的相互关系。在所有样品 B1 - B21 中获得基本横向模激光。

图 3 表示，为使最大光输出功率 P_k 不小于 100mW，必须选择满足直线 L 下面（包括直线 L）某一区域的条宽 W 和有效折射率差值 Δn ；

为使最大光输出功率 P_k 不小于 150mW, 则必须选择满足直线 M 下面(包括直线 M) 某一区域的条宽 W 和有效折射率差值 Δn 。

直线 L 用下式 (A1) 表示:

$$W = 1.6 \times 10^3 \times \Delta n [\mu m] + 9.3 [\mu m] \quad (A1)$$

5 直线 M 用下式 (A2) 表示:

$$W = 1.5 \times 10^3 \times \Delta n [\mu m] + 8.55 [\mu m] \quad (A2)$$

在该半导体激光器件中, 当半导体激光器件工作时, 由于载流子注入区域 a, 使区域 a 中的有效折射率约减小 10^{-3} 。因此, 为了保持有效折射率导向型结构良好, 有效折射率差值最好不小于 2×10^{-3} 。

10 尤其是, 就可靠性而言, 条宽 W 最好不小于 $3.0\mu m$ 。具体地说, 为使半导体激光器件的稳定工作时间不少于 1000 小时, 条宽 W 最好不小于 $3.0\mu m$ 。

如上所述, 为使基本横向模激光的最大光输出功率 P_k 不小于 100mW, 要如此选择条宽 W 和有效折射率差值 Δn 以满足下列关系:

$$15 \quad \Delta n \geq 2 \times 10^{-3},$$

$$W \leq 1.6 \times 10^3 \times \Delta n [\mu m] + 9.3 [\mu m],$$

$$W \geq 3.0 [\mu m]$$

为使基本横向模激光的最大光输出功率 P_k 不小于 150mW, 除了上述关系外, 最好还要满足下述关系:

$$20 \quad W \leq -1.5 \times 10^3 \times \Delta n [\mu m] + 8.55 [\mu m]$$

带隙大的电流阻挡层(它的 A1 的组分比较大)的结晶性较差, 结果, 在再次生长电流阻挡层过程中, 杂质会从该电流阻挡层扩散入有源层 6。此外, 为了把半导体激光器件做成一种有效折射率导向型半导体激光器件以减小无效电流, 把 p 型敷层 8 的厚度设定为很小的值, 最好不超过 0.25 μm 。所以, 为了防止上述的扩散现象, 最好把激活层 6 侧面的电流阻挡层 13 做成像本发明实施例中的非掺杂层那样的低杂质层, 更好是做成如上所述的非掺杂层。

在上述第一实施例中, 虽然把 $Al_qGa_{1-q}As$ ($q \geq 0$) 构成的单量子阱结构层用作有源层 6, 但是也可以把由 $Al_qGa_{1-q}As$ 阱层与 $Al_pGa_{1-p}As$ 阻挡层 ($p > q \geq 0$) 构成的多量子阱结构层用作为有源层 6。另外, 还可以把由 $Al_qGa_{1-q}As$ ($q \geq 0$) 构成的无量子效应层用作为有源层 6。

下面用图 4 和 5 说明根据本发明第二实施例的 AlGaAs 系半导体激光

器件。在图 4 所示的半导体激光器件中，对应于图 1 所示半导体激光器件部分的那些部分采用同样的标号。

在图 4 中，在 n 型 GAs 衬底 1 上依次形成 $0.5\mu\text{m}$ 厚 Se 掺杂 n 型 GAs 缓冲层 2、 $0.1\mu\text{m}$ 厚 Se 掺杂 n 型 $\text{Al}_s\text{Ga}_{1-s}\text{As}$ 缓冲层 3 以及 $2.2\mu\text{m}$ 厚 Se 掺杂 $\text{Al}_x\text{Ga}_{1-x}\text{As}$ 敷层 4，其中的 $x>s>0$ 。在本发明实施例中， $s=0.18$ ， $x=0.45$ 。

在 n 型敷层 4 上依次形成 200\AA 厚非掺杂的 $\text{Al}_v\text{Ga}_{1-v}\text{As}$ 光波导层 5、非掺杂的有源层 6 以及 200\AA 厚非掺杂的 $\text{Al}_w\text{Ga}_{1-w}\text{As}$ 光波导层 7，其中 $1>x>v$ 。在本实施例中， $v=0.35$ 。通过交替堆迭 80\AA 厚由 $\text{Al}_q\text{Ga}_{1-q}\text{As}$ 构成的量子阱层 6a 和 80\AA 厚由 $\text{Al}_p\text{Ga}_{1-p}\text{As}$ 构成的阻挡层 6b，构成有源层 6。这里， $v\geq p>q\geq 0$ ， $w\geq p>q\geq 0$ 。在本实施例中， $q=0.11$ ， $p=0.3$ 。此外， $y_1>w$ ， $y_2>w$ 。在本实施例中， $w=0.35$ 。

在光波导层 7 上形成 $t\mu\text{m}$ 厚 Zn 掺杂的 p 型 $\text{Al}_{y_1}\text{Ga}_{1-y_1}\text{As}$ 敷层。在实施例中， $y_1=0.45$ 。

在 p 型敷层 8 近中央部分上依次形成沿垂直方向（沿腔体长度方向）延伸的 200\AA 厚条形 Zn 掺杂的 p 型 $\text{Al}_u\text{Ga}_{1-u}\text{As}$ 蚀刻阻止层 9、 $1.8\mu\text{m}$ 厚条形 Zn 掺杂的 p 型 $\text{Al}_{y_2}\text{Ga}_{1-y_2}\text{As}$ 敷层 10 以及 $0.7\mu\text{m}$ 厚条形 Zn 掺杂的 p 型 GAs 盖层 11。p 型蚀刻阻止层 9 的宽度为 $W\mu\text{m}$ 。宽度 $W\mu\text{m}$ 成为形成电流路径的开口的宽度。这里， $1\geq u>y_1$ ， $1\geq u>y_2$ 。在本实施例中， $u=0.7$ ， $y_2=0.45$ 。p 型蚀刻阻止层 9、p 型敷层 10 和 p 型盖层 11 构成了条状脊形部分 12。

在 p 型敷层 8 上依次形成 $0.3\mu\text{m}$ 厚非掺杂的 $\text{Al}_{z_1}\text{Ga}_{1-z_1}\text{As}$ 电流阻挡层 13、 $0.2\mu\text{m}$ 厚 Se 掺杂的 n 型 $\text{Al}_{z_2}\text{Ga}_{1-z_2}\text{As}$ 电流阻挡层 14 以及 $0.3\mu\text{m}$ 厚 Se 掺杂的 n 型 GAs 电流阻挡层 15，从而覆盖住脊形部分 12 的侧表面，其中 $1\geq z_1>y_1$ ， $1\geq z_1>y_2$ ， $1\geq z_2>y_1$ ， $1\geq z_2>y_2$ 。

在 p 型盖层 11 的上表面、非掺杂电流阻挡层 13 的端面、n 型电流阻挡层 14 的端面以及 n 型电流阻挡层 15 的上表面与端面上，形成 $6\mu\text{m}$ 厚 Zn 掺杂的 p 型 GAs 接触层 16。

在 p 型接触层 16 上形成由 Cr/Au 组成的 P 侧电极 17，在 n 型衬底 1 的下表面上刷 Cr/Sn/Au 组成的 N 侧电极 18。

除了有源层 6 的详细结构之外，图 4 和图 1 所示的半导体激光器件的制造方法是相同的。

在该半导体激光器件中, 与 p 型敷层 8 和 10 相比, 具有条形开口(条宽为 W) 以便限制电流路径并形成该电流路径的电流阻挡层 13 和 14 具有较大的带隙和较小的折射率。因此, 在发光区(图 4 中以虚线椭圆表示的区域)内, 可以把对应于开口的区域 a 内的有效折射率做得比对应于开口两侧区域 b 内的有效折射率更大, 这样半导体激光器件就能像有效折射率导向型半导体激光器件那样工作了。

用上述结构, 电流阻挡层 13 和 14 成了对激光光线呈透明的透明的电流阻挡层。

通过选择电流阻挡层 13 和 14 各自的 A1 的组分比 z_1 和 z_2 、p 型敷层 8 的厚度 t 和条宽, 来改变在半导体激光器件不工作情况下的有效折射率差值 Δn (对应于开口区域 a 内的有效折射率 n_a 减去对应于开口两侧区域 b 内的有效折射率 n_b), 以测量可实现基本横向模激光时获得的最大光输出功率 P_k , 此时沿水平方向的水平光束发散角 θ_H 、COD (突然光学损坏) 以及像散性。结果列于表 3。在这种情况下, 在半导体激光器件的前后面上分别配上反射率为 12% 和 95% 的反射膜, 腔体长度设定为 $600 \mu m$, 在 $25^\circ C$ 环境温度下作测量。

表 3

编号	t (μm)	A1 的 组分比 $z_1=z_2$	Δn	W (μm)	基本横 向模激 光作用	θ 角度	P_k (mW)	COD (mW)	像散性 (μm)
C1	0.25	0.52	0.0020	4.5	○	5.6	115	190	35
C2	0.23	0.52	0.0024	4.8	○	5.6	95	175	9
C3	0.23	0.52	0.0024	4.0	○	5.5	120	180	7
C4	0.23	0.52	0.0024	3.2	○	5.9	145	185	7
C5	0.22	0.57	0.0028	5.0	○	5.6	70	200	8
C6	0.22	0.57	0.0028	4.3	○	6.0	100	185	6
C7	0.22	0.57	0.0028	3.5	○	6.5	110	180	5
C8	0.22	0.57	0.0028	3.2	○	7.0	120	150	5
C9	0.21	0.57	0.0031	4.6	○	6.1	70	180	7
C10	0.21	0.57	0.0031	3.8	○	7.0	100	170	5

编号	t (μm)	A1 的 组分比 z1=z2	Δn	W (μm)	基本横 向模激 光作用	θ 角度	Pk (mW)	CPD (mW)	像散性 (μm)
C11	0.21	0.57	0.0031	3.3	○	7.2	110	150	4
C12	0.21	0.57	0.0031	2.8	○	7.6	110	140	5
C13	0.21	0.57	0.0031	2.5	○	7.8	100	100	4
C14	0.21	0.57	0.0031	2.0	○	8.1	50	50	3
C15	0.20	0.52	0.0033	4.5	○	6.7	60	180	7
C16	0.20	0.52	0.0033	3.6	○	7.4	95	160	7
C17	0.20	0.52	0.0033	3.2	○	7.5	115	150	4
C18	0.19	0.57	0.0035	4.6	○	7.1	50	175	6
C19	0.17	0.57	0.0040	4.0	×	4.6	0	140	-
C20	0.15	0.57	0.0045	4.0	×	4.2	0	150	-

图 6 表示有效折射率差 Δn 、可实现基本横向模激光时获得的最大光输出功率 Pk、条宽 W 以及采用表 3 中编号 C1 - C18 样品获得的水平光束发散角 θ_H 之间的关系。

- 5 图 6 表明，为使最大光输出功率 Pk 不小于 70mW，必须选择满足虚线直线 A 与虚线直线 x 之间区域 RA 的条宽 W 与有效折射率差值 Δn ，而为了使最大光输出功率 Pk 不小于 100mW，则必须选择满足虚线直线 B 和上述直线 x 之间区域 RB 的条宽 W 与有效折射率差值 Δn 。

- 10 图 6 还说明，为使水平光束发散角 θ_H 不小于 6.5° ，必须选择满足实线直线 C 下面（包括直线 C）区域 RC 的条宽 W 与有效折射率差值 Δn ，而为了使水平光束发散角 θ_H 不小于 7° ，则必须选择满足实线直线 D 下面（包括直线 D）区域 RD 的条宽 W 与有效折射率差值 Δn 。

直线 A 由下式（B1）表示：

$$W = -1.33 \times 10^3 [\mu\text{m}] \times \Delta n + 8.723 [\mu\text{m}] \quad (\text{B1})$$

- 15 直线 B 由下式（B2）表示：

$$W = -1.33 \times 10^3 [\mu\text{m}] \times \Delta n + 7.923 [\mu\text{m}] \quad (\text{B2})$$

直线 X 由下式（B3）表示：

$$W = 2.5 [\mu\text{m}] \quad (\text{B3})$$

直线 C 由下式（B4）表示：

$$W = 2.25 \times 10^3 [\mu\text{m}] \times \Delta n - 2.8 [\mu\text{m}] \quad (\text{B4})$$

直线 D 由下式 (B5) 表示:

$$W = 2.25 \times 10^3 [\mu\text{m}] \times \Delta n - 3.175 [\mu\text{m}] \quad (\text{B5})$$

图 7 表示上述表 3 中所列出编号为 C9 - C14 样品的 COD 与条宽 W 之间的关系。

从图 7 和表 3 可看出, 当条宽 W 小于 $2.5\mu\text{m}$ 时, COD 小于 100mW , 只是最大光输出功率 P_k 小于 100mW , 这样就不能延长半导体激光器件的工作寿命。

图 8 表示上述表 3 中所列出的编号为 C1、C2、C5、C9 和 C18 的样品的像散性与有效折射率差值 Δn 之间的关系。

从图 8 和表 3 可看出, 当有效折射率差值 Δn 小于 2.4×10^{-3} 时, 像散性便迅速增大。这样, 在像散性很大时, 光头的光学设定操作就困难了。所以有效折射率差值 Δn 最好不小于 2.4×10^{-3} 。

另外, 如表 3 所示, 当有效折射率差值 Δn 超过 3.5×10^{-3} 时, 横向模激光就不稳定, 而难以得到基本横向模激光。因此, 有效折射率差值 Δn 最好不小 2.4×10^{-3} , 但不大于 3.5×10^{-3} 。

对于用作可再写光盘的光源的半导体激光器件, 希望最大光输出功率 P_k 不小于 70mW , 水平光束发散角 θ_H 不小于 6.5° 。所以在本发明中, 这样来选择条宽 W 和有效折射率差值 Δn , 使之适合于区域 RA 与区域 RC 相互交迭的某个区域, 且有效折射率差值 Δn 不小于 2.4×10^{-3} , 也不大于 3.5×10^{-3} 。

这就是说, 条宽 W 与有效折射率差值 Δn 满足下列方程:

$$2.4 \times 10^3 \leq \Delta n \leq 3.5 \times 10^{-3},$$

$$W \leq -1.33 \times 10^3 [\mu\text{m}] \times \Delta n + 8.723 [\mu\text{m}]$$

$$W \leq 2.25 \times 10^3 [\mu\text{m}] \times \Delta n - 2.8 [\mu\text{m}]$$

$$W \geq 2.5 [\mu\text{m}]$$

为使最大输出功率 P_k 不小于 100mW , 除了上述关系外, 最好还要满足下述关系:

$$W \leq -1.33 \times 10^3 [\mu\text{m}] \times \Delta n + 7.923 [\mu\text{m}]$$

为使水平光束发散角 Q_H 不小于 7° , 更要满足下述关系:

$$W \leq 2.25 \times 10^3 [\mu\text{m}] \times \Delta n - 3.175 [\mu\text{m}]$$

为使最大光输出功率 P_k 不小于 100mW , 且水平光束发散角 θ_H 不小

于 7°,最好还要满足下列关系:

$$2.4 \times 10^3 \leq \Delta n \leq 3.5 \times 10^{-3}$$

$$W \geq 2.5 [\mu\text{m}]$$

$$W \leq 1.33 \times 10^3 [\mu\text{m}] \times \Delta n - 0.323 [\mu\text{m}]$$

5 $W \leq 2.25 \times 10^3 [\mu\text{m}] \times \Delta n - 3.175 [\mu\text{m}]$

此外,带隙大的电流阻挡层(其 Al 的组分比较大)的结晶性较差,结果在再次生长电流阻挡层的过程中,杂质会从电流阻挡层扩散入有源层 6。再者,p 型敷层 8 的厚度设成很小的值,最好不超过 $0.25 \mu\text{m}$,以把半导体激光器件做成有效折射率导向型半导体激光器件,以减小无
10 效电流。所以,为防止出现上述的扩散现象,最好把有源层 6 侧边的电流阻挡层 13 做成本实施例中诸如非掺杂层那样的低杂质层,更好是像上述那样做成非掺杂层。

在上述第二实施例中,虽然用由 $\text{Al}_q\text{Ga}_{1-q}\text{As}$ 量子阱层和 $\text{Al}_p\text{Ga}_{1-p}\text{As}$ 阻挡层($p>q\geq 0$)构成的多量子阱结构层作为有源层 6,但是也可使用由
15 $\text{Al}_q\text{Ga}_{1-q}\text{As}(q\geq 0)$ 构成的单量子阱层。另外,还可使用由 $\text{Al}_q\text{Ga}_{1-q}\text{As}(q\geq 0)$ 构成的无量子效应的层。

在上述第一与第二实施例中,虽然在 p 型敷层 8 与 10 之间即 p 型敷层中存在蚀刻阻止层 9,但是只要成品率下降能允许的话,就不必设置蚀刻阻止层 9。

20 在上述第一和第二实施例中,AlGaAs 敷层 4、8 和 10 各自的 Al 的组分比 x 、 y_1 和 y_2 ,可在不小于 0.4 和不大于 0.6 的范围内作适当选择;电流阻挡层 13 和 14 各自的 Al 的组分比 z_1 与 z_2 大于 AlGaAs 敷层 8 和 10 各自的 Al 组分比 y_1 和 y_2 ,它们具有预定宽度的条形开口用于限制电流路径并形成该电流路径且相互邻近,被设定成至少比 AlGaAs
25 敷层 8 和 10 各自的 Al 的组分比 y_1 和 y_2 大 0.02。

然而,实验证明,若 AlGaAs 的 Al 的组分比大于 0.6,则其结晶性就差且易于氧化,在其上便难以进行晶体生长。所以,最好把电流阻挡层 13 和 14 各自的 Al 的组分比 z_1 与 z_2 设成不大于 0.6。

再者,在上述第一和第二实施例中,虽然 n 型 AlGaAs 电流阻挡层 14
30 和非掺杂电流阻挡层 13 的 Al 的组分比相同,但是也可以有不同的 Al 的组分比。此外,半导体激光器件可以只包括电流阻挡层 13 和 14 中的一个电流阻挡层。

虽然已经详细说明和示例了本发明内容，但是显然应该理解，这些说明和示例只是作为举例而并非限制，本发明的精神和范围只受限制于所附的权利要求的各条款。

说明书附图

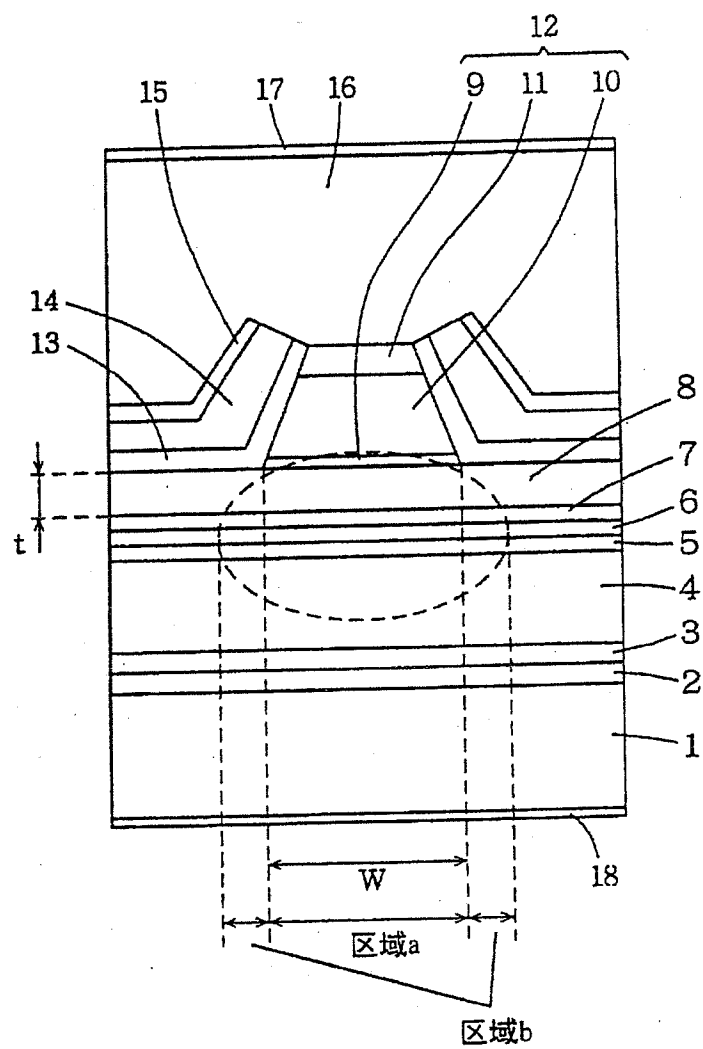


图 1

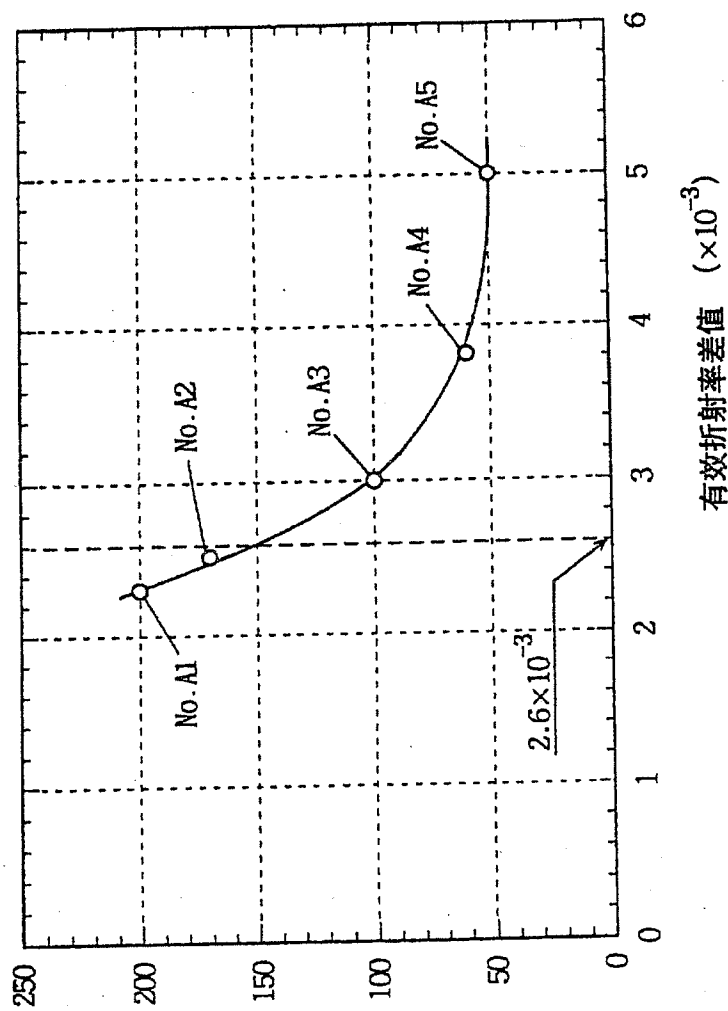


图 2

基本横向模激光的最大
光输出功率 (mW)

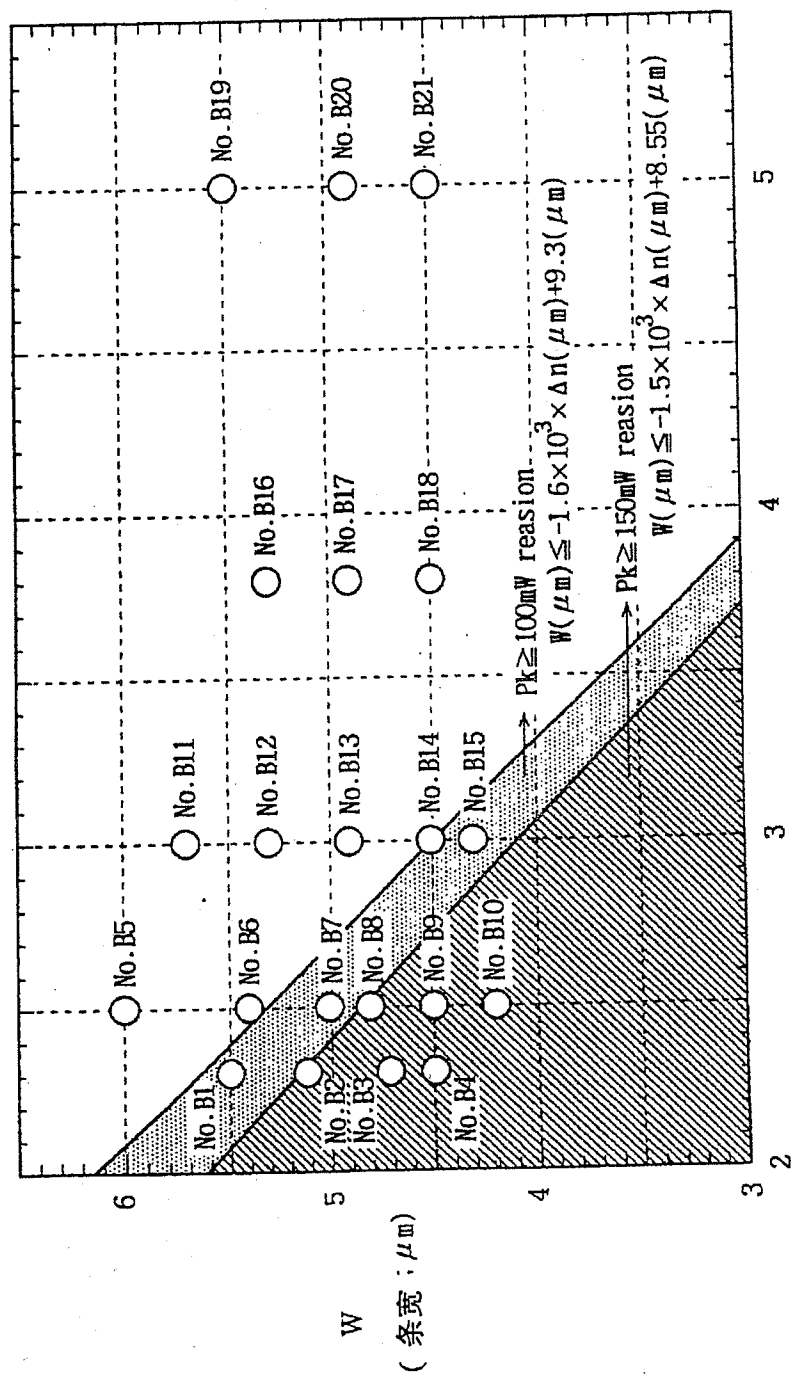


图 3

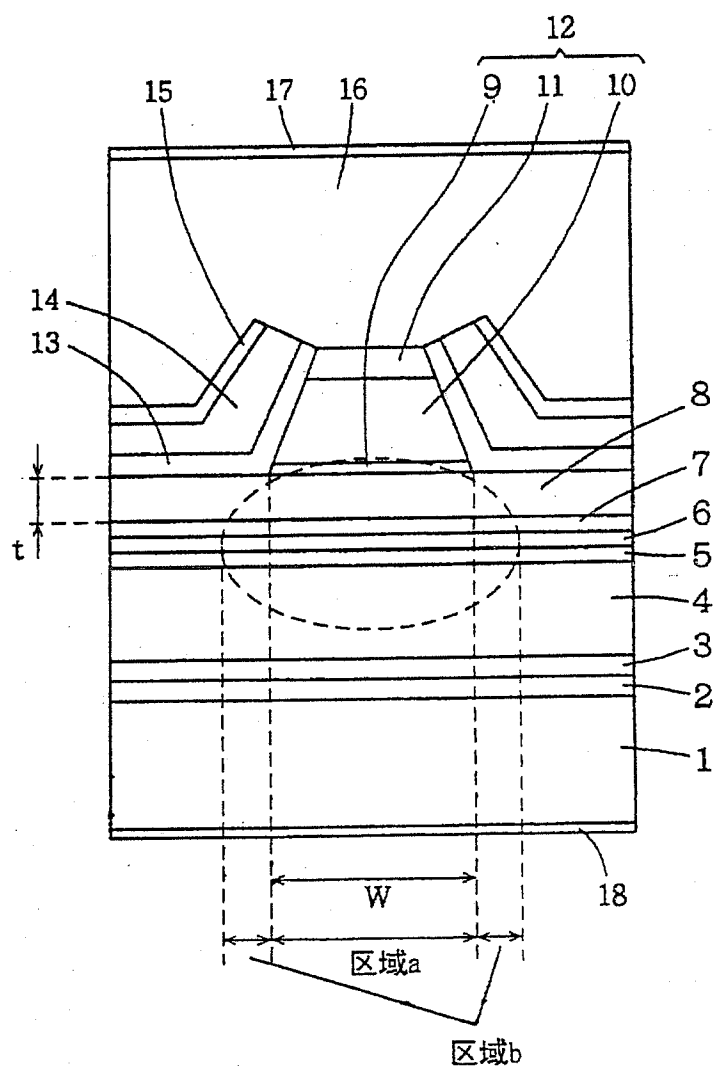


图 4

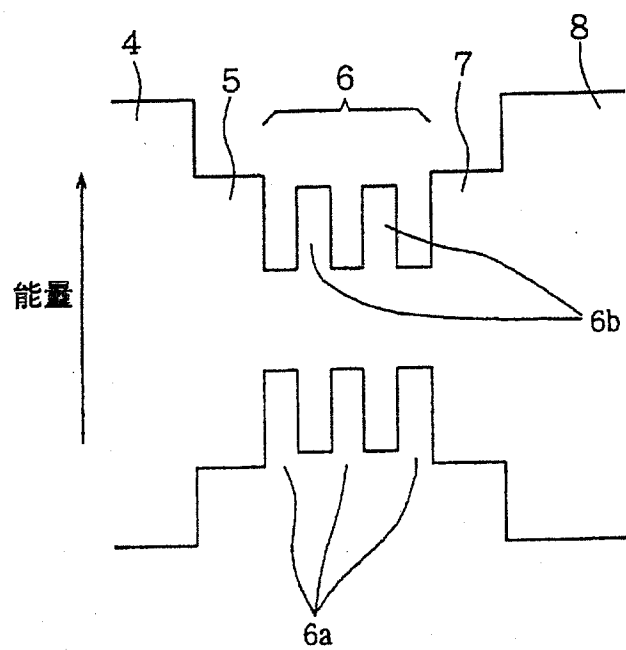


图 5



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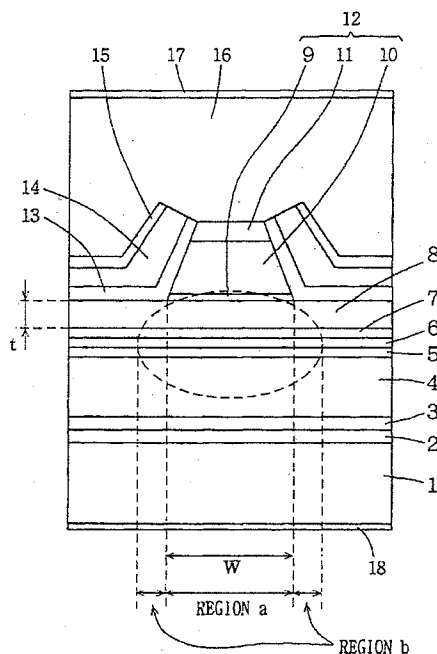
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(54) **Semiconductor laser device and method of designing the same**

(57) A semiconductor laser device comprises a cladding layer of a first conductivity type, an active layer, a cladding layer of a second conductivity type, and a current blocking layer having a stripe-shaped opening having a predetermined width W for restricting a current path and forming the current path, and having a larger band gap than that of the cladding layer of the second conductivity type and having a smaller refractive index than that of the cladding layer of the second conductivity type. A difference Δn between a real refractive index in a region, which corresponds to the opening, in the active layer and a real refractive index in a region, which corresponds to both sides of the opening, in the active layer and the width W [μm] of the opening are so set as to satisfy a predetermined relationship. The difference Δn between the real refractive indexes is set by selecting the Al composition ratio of the current blocking layer and the thickness of the cladding layer of the second conductivity type on the both sides of the opening.

FIG. 1



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Description

The present invention relates to a semiconductor laser device and a method of designing the same.

In recent years, semiconductor laser devices operable at a low operating current have been actively studied and developed. IEEE JOURNAL OF SELECTED TOPICS IN QUANTUM ELECTRONICS, VOL.1, NO.2, PP.102-109, 1995 has reported that in a real refractive index guided semiconductor laser employing a transparent current blocking layer, its operating current can be reduced.

In such a real refractive index guided semiconductor laser device, it is considered that a transverse mode is stabilized when a real refractive index difference is large to some extent. For example, in the above-mentioned document, the real refractive index difference is approximately 5×10^{-3} .

In the above-mentioned real refractive index guided semiconductor laser device employing a transparent current blocking layer, however, it is difficult to make light output power higher in fundamental transverse mode lasing.

Furthermore, in the above-mentioned real refractive index guided semiconductor laser device, the loss inside of a cavity can be decreased, whereby high light output power is possible. When the semiconductor laser device is used in an optical pickup as a light source for a rewritable optical disc such as a magneto-optical disc or a phase change disc, however, realization of higher light output power of the semiconductor laser device is required. In addition, when writing at more than fourfold speed, it is desired that with respect to the output power of the laser device, maximum light output power is not less than 70 mW in fundamental transverse mode lasing, and a horizontal beam divergence θ_H in the horizontal direction is not less than 6.5° in order to reduce noise characteristics or the like in a case where the semiconductor device is carried by the optical pickup.

An object of the present invention is to provide a semiconductor laser device capable of obtaining high light output power in fundamental transverse mode lasing and a method of designing the same.

Another object of the present invention is to provide a semiconductor laser device capable of increasing maximum light output power in fundamental transverse mode lasing and increasing a horizontal beam divergence θ_H in the horizontal direction and a method of designing the same.

A semiconductor laser device according to the present invention comprises a cladding layer of a first conductivity type, an active layer, a cladding layer of a second conductivity type, and a current blocking layer having a stripe-shaped opening of a predetermined width for restricting a current path and forming the current path, and having a larger band gap than that of the cladding layer of the second conductivity type and having a lower refractive index than that of the cladding layer of the second conductivity type in this order, the cladding layer of the second conductivity type having a flat portion and a stripe-shaped ridge portion on the flat portion, the ridge portion being positioned in the opening of the current blocking layer, the current blocking layer being so formed as to cover the upper surface of the flat portion and the side surface of the ridge portion, and a difference Δn between a real refractive index in a region, which corresponds to the opening, in the active layer (that is, a region, which faces the opening, in a light emitting region or/and a region, which includes the opening, in the light emitting region) and a real refractive index in a region, which corresponds to both sides of the opening, in the active layer (that is, a region, which faces to both sides of the opening, in the light emitting region or/and a region, which includes both sides of the opening, in the light emitting region) and the width W [μm] of the opening satisfying the following relationship:

$$\Delta n \geq 2 \times 10^{-3},$$

$$W \leq -1.6 \times 10^3 \times \Delta n + 9.3,$$

and

$$W \geq 3.0$$

In this case, a so-called ridge wave guided semiconductor laser device is provided. The width of the ridge portion at a distance away from the active layer may decrease as the distance increases.

In the semiconductor laser device, high light output power can be obtained at a low operating current and in fundamental transverse mode lasing. For example, it is possible to obtain light output power of not less than 100 mW.

Since the difference Δn between the real refractive indexes is not less than 2×10^{-3} , a real refractive index guided structure is kept good. Since the width W of the opening is not less than $3.0 \mu\text{m}$, high reliability is obtained.

It is more preferable that the difference Δn between the real refractive indexes and the width W of the opening satisfy the following relationship:

$$W \leq -1.5 \times 10^3 \times \Delta n + 8.55$$

In this case, light output power of not less than 150 mW is obtained in fundamental transverse mode lasing.

The cladding layer of the first conductivity type may be composed of $\text{Al}_x\text{Ga}_{1-x}\text{As}$, the active layer may be composed of $\text{Al}_q\text{Ga}_{1-q}\text{As}$ ($1 > x > q \geq 0$), the cladding layer of the second conductivity type may be composed of $\text{Al}_y\text{Ga}_{1-y}\text{As}$ ($y > q$), and the current blocking layer may be composed of $\text{Al}_z\text{Ga}_{1-z}\text{As}$.

In this case, high light output power is obtained at a low operating current and in fundamental transverse mode lasing. For example, it is possible to obtain light output power of not less than 100 mW in fundamental transverse mode lasing.

The difference Δn between the real refractive indexes may be set by selecting the Al composition ratio z of the current blocking layer and the thickness of the cladding layer of the second conductivity type on the both sides of the opening.

It is preferable that the Al composition ratio x of the cladding layer of the first conductivity type and the Al composition ratio y of the cladding layer of the second conductivity type are not less than 0.4 nor more than 0.6.

It is preferable that the Al composition ratio z of the current blocking layer is higher than the Al composition ratio y of the cladding layer of the second conductivity type. It is more preferable that the difference between the Al composition ratio z of the current blocking layer and the Al composition ratio y of the cladding layer of the second conductivity type is not less than 0.02. In this case, it is possible to easily realize a good difference between the real refractive indexes.

It is preferable that the Al composition ratio z of the current blocking layer is not more than 0.6. Consequently, the crystallinity of the current blocking layer is increased, whereby the crystallinity of a layer formed on the current blocking layer is also increased. As a result, it is possible to provide a semiconductor laser device with high reliability.

It is preferable that the current blocking layer comprises at least a layer of the first conductivity type. In this case, the layer of the first conductivity type in the current blocking layer and the cladding layer of the second conductivity type are of opposite conductivity types, whereby sufficient current blocking is possible. The current blocking layer may be constituted by only the layer of the first conductivity type.

The current blocking layer may comprise a first layer formed on the active layer and a second layer formed on the first layer, the second layer may be of the first conductivity type, and the first layer may have a lower impurity concentration than that of the second layer. In this case, impurities can be prevented from being diffused into the active layer from the current blocking layer. Particularly, it is preferable that the first layer is an undoped layer.

When the current blocking layer is constituted by the layer of the first conductivity type, the impurity concentration of the current blocking layer at a distance away from the active layer may decrease as the distance decreases.

Another layer having a thickness of not more than 300 Å such as an etching stop layer may exist in the cladding layer of the second conductivity type because the difference between the real refractive indexes is hardly affected.

Furthermore, a current blocking layer of the first conductivity type absorbing lasing light may be provided on the current blocking layer.

It is preferable that the cladding layer of the first conductivity type is formed on a semiconductor substrate of the first conductivity type. In the AlGaAs system semiconductor laser device, it is preferable to use a GaAs substrate.

The active layer may have a single quantum well structure composed of a single quantum well layer, may have a multi quantum well structure constructed by alternately stacking quantum well layers and barrier layers, or may be a single layer having no quantum effect.

The multi quantum well structure of the AlGaAs system semiconductor laser device may comprise quantum well layers composed of $\text{Al}_q\text{Ga}_{1-q}\text{As}$ ($1 > x > q \geq 0$, $1 > y > q \geq 0$) and barrier layers composed of $\text{Al}_p\text{Ga}_{1-p}\text{As}$ ($x \geq p > q$, $y \geq p > q$).

It is preferable that the semiconductor laser device achieves light output power of not less than 100 mW in fundamental transverse mode lasing. It is more preferable that the semiconductor laser device achieves light output power of not less than 150 mW in fundamental transverse mode lasing.

A method of designing a semiconductor laser device according to another aspect of the present invention is a method of designing a semiconductor laser device comprising a cladding layer of a first conductivity type composed of $\text{Al}_x\text{Ga}_{1-x}\text{As}$, an active layer composed of $\text{Al}_q\text{Ga}_{1-q}\text{As}$ ($1 > x > q \geq 0$), a cladding layer of a second conductivity type composed of $\text{Al}_y\text{Ga}_{1-y}\text{As}$ ($y > q$), and a current blocking layer having a stripe-shaped opening of a predetermined width for restricting a current path and forming the current path and composed of $\text{Al}_z\text{Ga}_{1-z}\text{As}$ ($1 \geq z > y$) in this order, which comprises the steps of setting a difference Δn between a real refractive index in a region, which corresponds to the opening, in the active layer and a real refractive index in a region, which corresponds to both sides of the opening, in the active layer and the width W of the opening in order that predetermined light output power is obtained in fundamental transverse mode lasing, and selecting the Al composition ratio z of the current blocking layer and the thickness of the cladding layer of the second conductivity type on the both sides of the opening in order that the difference Δn between

the real refractive indexes is obtained.

Consequently, a semiconductor laser device achieving high light output power at a low operating current and in fundamental transverse mode lasing is obtained.

It is preferable that the setting step comprises the step of setting the difference Δn between the real refractive indexes and the width W [μm] of the opening in order to satisfy the following relationships:

$$\Delta n \geq 2 \times 10^{-3},$$

and

$$W \leq -1.6 \times 10^3 \times \Delta n + 9.3$$

Consequently, a semiconductor laser device achieving light output power of not less than 100 mW in fundamental transverse mode lasing is obtained.

It is more preferable that the setting step comprises the step of setting the difference Δn between the real refractive indexes and the width W [μm] of the opening in order to satisfy the following relationship:

$$W \leq -1.5 \times 10^3 \times \Delta n + 8.55$$

Consequently, a semiconductor laser device achieving light output power of not less than 150 mW in fundamental transverse mode lasing is obtained.

It is preferable that the setting step comprises the step of setting the width W of the opening to not less than 3.0 μm . Consequently, a semiconductor laser device with high reliability is obtained.

The cladding layer of the second conductivity type may comprise a flat portion and a stripe-shaped ridge portion on the flat portion, the ridge portion may be positioned in the opening of the current blocking layer, and the current blocking layer may be so formed as to cover the upper surface of the flat portion and the side surface of the ridge portion. In this case, a so-called ridge wave guided semiconductor laser device is provided. The width of the ridge portion at a distance away from the active layer may decrease as the distance increases.

A semiconductor laser device according to still another aspect of the present invention comprises a cladding layer of a first conductivity type, an active layer, a cladding layer of a second conductivity type, and a current blocking layer having a stripe-shaped opening of a predetermined width for restricting a current path and forming the current path, and having a larger band gap than that of the cladding layer of the second conductivity type and having a smaller refractive index than that of the cladding layer of the second conductivity type in this order, the cladding layer of the second conductivity type having a flat portion and a stripe-shaped ridge portion on the flat portion, the ridge portion being positioned in the opening of the current blocking layer, the current blocking layer being so formed as to cover the upper surface of the flat portion and the side surface of the ridge portion, and a difference Δn between a real refractive index in a region, which corresponds to the opening, in the active layer and a real refractive index in a region, which corresponds to both sides of the opening, in the active layer and the width W [μm] of the opening satisfying the following relationships:

$$2.4 \times 10^{-3} \leq \Delta n \leq 3.5 \times 10^{-3},$$

$$W \geq 2.5,$$

$$W \leq -1.33 \times 10^3 \times \Delta n + 8.723,$$

and

$$W \leq 2.25 \times 10^3 \times \Delta n - 2.8$$

In this case, a so-called ridge wave guided semiconductor laser device is provided. The width of the ridge portion

at a distance away from the active layer may decrease as the distance increases.

In the semiconductor laser device according to the present invention, high maximum light output power and a large horizontal beam divergence can be obtained in fundamental transverse mode lasing. It is possible to increase the maximum light output power to not less than 70 mW, for example, in fundamental transverse mode lasing as well as to increase the horizontal beam divergence to not less than 6.5° , for example.

It is more preferable that the difference Δn between the real refractive indexes and the width W [μm] of the opening satisfy the following relationship:

$$W \leq -1.33 \times 10^3 \times \Delta n + 7.923$$

In this case, maximum light output power of not less than 100 mW is achieved in fundamental transverse mode lasing.

It is more preferable that the difference Δn between the real refractive indexes and the width W [μm] of the opening satisfy the following relationship:

$$W \leq 2.25 \times 10^3 \times \Delta n - 3.175$$

In this case, it is possible to increase the horizontal beam divergence to not less than 7° .

The cladding layer of the first conductivity type may be composed of $\text{Al}_x\text{Ga}_{1-x}\text{As}$, the active layer may be composed of $\text{Al}_q\text{Ga}_{1-q}\text{As}$ ($1 > x > q \geq 0$), the cladding layer of the second conductivity type may be composed of $\text{Al}_y\text{Ga}_{1-y}\text{As}$ ($y > q$), and the current blocking layer may be composed of $\text{Al}_z\text{Ga}_{1-z}\text{As}$.

In this case, maximum light output power of not less than 70 mW can be obtained in fundamental transverse mode lasing, and the horizontal beam divergence can be not less than 6.5° .

The difference Δn between the real refractive indexes may be set by selecting the Al composition ratio z of the current blocking layer and the thickness of the cladding layer of the second conductivity type on the both sides of the opening.

It is preferable that the Al composition ratio x of the cladding layer of the first conductivity type and the Al composition ratio y of the cladding layer of the second conductivity type are not less than 0.4 nor more than 0.6.

It is preferable that the Al composition ratio z of the current blocking layer is higher than the Al composition ratio y of the cladding layer of the second conductivity type. It is more preferable that a difference between the Al composition ratio z of the current blocking layer and the Al composition ratio y of the cladding layer of the second conductivity type is not less than 0.02. In this case, it is possible to easily realize a good difference between the real refractive indexes.

It is preferable that the Al composition ratio z of the current blocking layer is not more than 0.6. Consequently, the crystallinity of the current blocking layer is increased, whereby the crystallinity of a layer formed on the current blocking layer is also increased. As a result, it is possible to provide a semiconductor laser device with high reliability.

It is preferable that the current blocking layer comprises at least a layer of the first conductivity type. In this case, the layer of the first conductivity type in the current blocking layer and the cladding layer of the second conductivity type are of opposite conductivity types, whereby sufficient current blocking is possible. The current blocking layer may be constituted by only the layer of the first conductivity type.

The current blocking layer may comprise a first layer formed on the active layer and a second layer formed on the first layer, the second layer may be of the first conductivity type, and the first layer may have a lower impurity concentration than that of the second layer. In this case, impurities can be prevented from being diffused into the active layer from the current blocking layer. Particularly, it is preferable that the first layer is an undoped layer.

When the current blocking layer is constituted by the layer of the first conductivity type, the impurity concentration of the current blocking layer at a distance away from the active layer may decrease as the distance decreases.

Another layer having a thickness of not more than 300 Å such as an etching stop layer may exist in the cladding layer of the second conductivity type because the difference between the real refractive indexes is hardly affected.

Furthermore, a current blocking layer of the first conductivity type absorbing lasing light may be provided on the current blocking layer.

It is preferable that the cladding layer of the first conductivity type is formed on a semiconductor substrate of the first conductivity type. In the AlGaAs system semiconductor laser device, it is preferable to use a GaAs substrate.

The active layer may have a single quantum well structure composed of a single quantum well layer, may have a multi quantum well structure constructed by alternately stacking quantum well layers and barrier layers, or may be a single layer having no quantum effect.

The multi quantum well structure of the AlGaAs system semiconductor laser device may comprise quantum well layers composed of $\text{Al}_q\text{Ga}_{1-q}\text{As}$ ($1 > x > q \geq 0$, $1 > y > q \geq 0$) and barrier layers composed of $\text{Al}_p\text{Ga}_{1-p}\text{As}$ ($x \geq p > q$, y

$\geq p > q$).

It is preferable that the semiconductor laser device achieves maximum light output power of not less than 70 mW in fundamental transverse mode lasing. It is more preferable that the semiconductor laser device achieves maximum light output power of not less than 100 mW in fundamental transverse mode lasing. On the other hand, it is preferable that the semiconductor laser device achieves a horizontal beam divergence of not less than 6.5° . It is more preferable that the semiconductor laser device achieves a horizontal beam divergence of not less than 7° .

As a beam approximates to a complete round, optical setting in an optical pickup can be facilitated. Since a vertical beam divergence is larger than the horizontal beam divergence, for example, approximately 15 to 30° , the horizontal beam divergence may be large to the same extent as the vertical beam divergence.

Additionally, as the cavity length decreases, the horizontal beam divergence can be made slightly larger. On the other hand, if the cavity length is less than approximately $300\text{ }\mu\text{m}$, the level of COD (catastrophic optical damage) decreases. Consequently, it is preferable that the cavity length is in the range of not less than $300\text{ }\mu\text{m}$ nor more than $600\text{ }\mu\text{m}$.

A method of designing a semiconductor laser device according to a further aspect of the present invention is a method of designing a semiconductor laser device comprising a cladding layer of a first conductivity type composed of $\text{Al}_x\text{Ga}_{1-x}\text{As}$, an active layer composed of $\text{Al}_q\text{Ga}_{1-q}\text{As}$ ($1 > x > q \geq 0$), a cladding layer of a second conductivity type composed of $\text{Al}_y\text{Ga}_{1-y}\text{As}$ ($y > q$), and a current blocking layer having a stripe-shaped opening of a predetermined width for restricting a current path and forming the current path and composed of $\text{Al}_z\text{Ga}_{1-z}\text{As}$ ($1 \geq z > y$) in this order, which comprises the steps of setting a difference Δn between a real refractive index in a region, which corresponds to the opening, in the active layer and a real refractive index in a region, which corresponds to both sides of the opening, in the active layer and the width W of the opening in order that predetermined maximum light output power and a predetermined horizontal beam divergence are obtained in fundamental transverse mode lasing, and selecting the Al composition ratio z of the current blocking layer and the thickness of the cladding layer of the second conductivity type on the both sides of the opening in order that the difference Δn between the real refractive indexes is obtained.

Consequently, a semiconductor laser achieving high maximum light output power in fundamental transverse mode lasing and a large horizontal beam divergence is obtained.

It is preferable that the setting step comprises the step of setting the difference Δn between the real refractive indexes and the width W [μm] of the opening in order to satisfy the following relationships:

$$2.4 \times 10^{-3} \leq \Delta n \leq 3.5 \times 10^{-3},$$

$$W \geq 2.5,$$

$$W \leq -1.33 \times 10^3 \times \Delta n + 8.723,$$

and

$$W \leq 2.25 \times 10^3 \times \Delta n - 2.8$$

Consequently, a semiconductor laser device achieving maximum light output power of not less than 70 mW in fundamental transverse mode lasing and a horizontal beam divergence of not less than 6.5° is obtained.

It is more preferable that the setting step comprises the step of setting the difference Δn between the real refractive indexes and the width W [μm] of the opening in order to satisfy the following relationship:

$$W \leq -1.33 \times 10^3 \times \Delta n + 7.923$$

In this case, a semiconductor laser device achieving maximum light output power of not less than 100 mW in fundamental transverse mode lasing is obtained.

It is preferable that the setting step comprises the step of setting the difference Δn between the real refractive indexes and the width W [μm] of the opening in order to satisfy the following relationship:

$$W \leq 2.25 \times 10^3 \times \Delta n - 3.175$$

In this case, a semiconductor laser device achieving a horizontal beam divergence of not less than 7° is obtained.

The cladding layer of the second conductivity type may comprise a flat portion and a stripe-shaped ridge portion on the flat portion. The ridge portion may be positioned in the opening of the current blocking layer, and the current blocking layer may be so formed as to cover the upper surface of the flat portion and the side surface of the ridge portion. In this case, a so-called ridge wave guided semiconductor laser device is provided. The width of the ridge portion at a distance away from the active layer may decrease as the distance increases.

The foregoing and other objects, features, aspects and advantages of the present invention will become more apparent from the following detailed description of the present invention when taken in conjunction with the accompanying drawings.

Fig. 1 is a schematic cross-sectional view of a semiconductor laser device according to a first embodiment of the present invention;

Fig. 2 is a diagram showing the relationship between a real refractive index difference Δn and maximum light output power P_k obtained when fundamental transverse mode lasing is possible in the semiconductor laser device shown in Fig. 1;

Fig. 3 is a diagram showing the relationship among a real refractive index difference Δn , maximum light output power P_k obtained when fundamental transverse mode lasing is possible, and a stripe width W in the semiconductor laser device shown in Fig. 1;

Fig. 4 is a schematic cross-sectional view of a semiconductor laser device according to a second embodiment of the present invention;

Fig. 5 is a diagram showing a schematic band structure in an active layer and the vicinity thereof in the semiconductor laser device shown in Fig. 4;

Fig. 6 is a diagram showing the relationship among a real refractive index difference Δn , maximum light output power P_k obtained when fundamental transverse mode lasing is possible, a stripe width W , and a horizontal beam divergence θ_H in the semiconductor laser device shown in Fig. 4;

Fig. 7 is a diagram showing the relationship between a stripe width W and COD (catastrophic optical damage) in the semiconductor laser device shown in Fig. 4; and

Fig. 8 is a diagram showing the relationship between a real refractive index difference Δn and astigmatism in the semiconductor laser device shown in Fig. 4.

An AlGaAs system semiconductor laser device according to a first embodiment of the present invention will be described using Fig. 1.

In Fig. 1, an Se doped n-type GaAs buffer layer 2 having a thickness of $0.5 \mu\text{m}$, an Se doped n-type $\text{Al}_s\text{Ga}_{1-s}\text{As}$ buffer layer 3 having a thickness of $0.1 \mu\text{m}$, and an Se doped n-type $\text{Al}_x\text{Ga}_{1-x}\text{As}$ cladding layer 4 having a thickness of $2.3 \mu\text{m}$ are formed in this order on an n-type GaAs substrate 1, where $x > s > 0$. In the present embodiment, $s = 0.18$ and $x = 0.45$.

An undoped $\text{Al}_v\text{Ga}_{1-v}\text{As}$ optical guide layer 5 having a thickness of 410 \AA , an undoped active layer 6 having a single quantum well structure composed of $\text{Al}_q\text{Ga}_{1-q}\text{As}$ having a thickness of 100 \AA , and an undoped $\text{Al}_w\text{Ga}_{1-w}\text{As}$ optical guide layer 7 having a thickness of 410 \AA are formed in this order on the n-type cladding layer 4, where $1 > x > v$, $v > q \geq 0$ and $w > q \geq 0$, and $y_1 > w$ and $y_2 > w$. In the present embodiment, $v = 0.35$, $q = 0.035$, and $w = 0.35$.

A Zn doped p-type $\text{Al}_{y_1}\text{Ga}_{1-y_1}\text{As}$ cladding layer 8 having a thickness of $t \mu\text{m}$ is formed on the optical guide layer 7. In the present embodiment, $y_1 = 0.45$.

A stripe-shaped Zn doped p-type $\text{Al}_u\text{Ga}_{1-u}\text{As}$ etching stop layer 9 having a thickness of 200 \AA extending in the vertical direction (in the direction of the cavity length), a stripe-shaped Zn doped p-type $\text{Al}_{y_2}\text{Ga}_{1-y_2}\text{As}$ cladding layer 10 having a thickness of $2 \mu\text{m}$, and a stripe-shaped Zn doped p-type GaAs cap layer 11 having a thickness of $0.4 \mu\text{m}$ are formed in this order on an approximately central part of the p-type cladding layer 8. The p-type etching stop layer 9 has a width $W \mu\text{m}$. The width $W \mu\text{m}$ becomes the width of an opening forming a current path. Here, $1 > u > y_1$ and $1 \geq u > y_2$. In the present embodiment, $u = 0.7$ and $y_2 = 0.45$. The p-type etching stop layer 9, the p-type cladding layer 10, and p-type cap layer 11 constitute a stripe-shaped ridge portion 12.

An undoped $\text{Al}_{z_1}\text{Ga}_{1-z_1}\text{As}$ current blocking layer 13 having a thickness of $0.3 \mu\text{m}$, an Se doped n-type $\text{Al}_{z_2}\text{Ga}_{1-z_2}\text{As}$ current blocking layer 14 having a thickness of $0.2 \mu\text{m}$, and an Se doped n-type GaAs current blocking layer 15 having a thickness of $0.3 \mu\text{m}$ are formed in this order on the p-type cladding layer 8 so as to cover the side surface of the ridge portion 12, where $1 \geq z_1 > y_1$, $1 \geq z_1 > y_2$, $1 \geq z_2 > y_1$, and $1 \geq z_2 > y_2$.

A Zn doped p-type GaAs contact layer 16 having a thickness of $6 \mu\text{m}$ is formed on the upper surface of the p-type cap layer 11, the end surface of the undoped current blocking layer 13, the end surface of the n-type current blocking layer 14, and the upper surface and the end surface of the n-type current blocking layer 15.

A p-side electrode 17 composed of Cr/Au is formed on the p-type contact layer 16, and an n-side electrode 18 composed of Cr/Sn/Au is formed on the lower surface of the n-type substrate 1.

Description is now made of one example of a method of fabricating the above-mentioned semiconductor laser device.

First, the n-type GaAs buffer layer 2, the n-type AlGaAs buffer layer 3, the n-type AlGaAs cladding layer 4, the undoped AlGaAs optical guide layer 5, the undoped active layer 6, the undoped AlGaAs optical guide layer 7, the p-type AlGaAs cladding layer (a flat portion) 8, the p-type AlGaAs or AlAs etching stop layer 9, the p-type cladding layer (corresponding to a ridge portion formed later) 10, and the p-type GaAs cap layer 11 are continuously grown on the n-type GaAs substrate 1 by the vapor phase epitaxy (VPE) method such as the metal organic chemical vapor deposition (MOCVD) method or the molecular beam epitaxy (MBE) method. The p-type cap layer 11 is a protective layer for preventing the impossibility of crystal growth on the p-type cladding layer 10 by exposure and oxidation of the p-type cladding layer 10 in the fabrication processes.

A stripe-shaped SiO_2 film is then formed on the p-type GaAs cap layer 11, and the layers under the p-type etching stop layer 9 are selectively etched away using the SiO_2 film as a mask, after which the etching stop layer 9 is also etched away with the SiO_2 film used as the mask, to form the ridge portion 12. Since the etching stop layer 9 has a high Al composition ratio, it is difficult to grow a crystal having good crystallinity on the etching stop layer 9 after the etching step. Therefore, the etching stop layer 9 is removed in the present embodiment.

The current blocking layers 13, 14, and 15 are then continuously grown in this order by the above-mentioned vapor phase epitaxy method on the cladding layer 8 so as to cover the side surface of the ridge portion 12, to expose the upper surface of the cap layer 11. Thereafter, the p-type GaAs contact layer 16 is grown by the above-mentioned vapor phase epitaxy method on the upper surfaces of the current blocking layers 13, 14 and 15 and the cap layer 11.

In the semiconductor laser device, the current blocking layers 13 and 14 having a stripe-shaped opening (having a stripe width W) for restricting a current path as well as forming the current path have larger band gaps and smaller refractive indexes than those of the p-type cladding layers 8 and 10. Consequently, in a light emitting region (a region schematically indicated by an ellipse of a dotted line in Fig. 1), a real refractive index in a region a corresponding to the opening can be made larger than a real refractive index in a region b corresponding to both sides of the opening. Consequently, the semiconductor laser device is operable as a real refractive index guided semiconductor laser device. A real refractive index difference means a difference between the refractive index of light having a lasing wavelength sensed in the region a and the refractive index of the light sensed in the region b.

By the above-mentioned construction, the current blocking layers 13 and 14 become transparent current blocking layers which are transparent to lasing light.

The real refractive index difference in a case where the semiconductor laser device is not operated (the real refractive index in the region a corresponding to the opening minus the real refractive index in the region b corresponding to both sides of the opening) is changed by selecting the respective Al composition ratios z_1 and z_2 of the current blocking layers 13 and 14 or the thickness t of the cladding layer 8, to measure maximum light output power in fundamental transverse mode lasing. The results are shown in Fig. 2. In this case, a reflective film having an index of reflection of 2 % and a reflective film having an index of reflection of 95 % are respectively provided on a front facet and a rear facet of the semiconductor laser device, and the cavity length is set to 1200 μm , to make measurements at an ambient temperature of 25 °C. The respective Al composition ratios z_1 and z_2 of the current blocking layers 13 and 14 and the thickness t of the p-type cladding layer 8 at respective points shown in Fig. 2 are shown in Table 1. The stripe widths of samples Nos. A1 to A5 are 4.5 μm .

Table 1

No.	Al COMPOSITION RATIO z_1 OF CURRENT BLOCKING LAYER 13	Al COMPOSITION RATIO z_2 OF CURRENT BLOCKING LAYER 14	THICKNESS t OF p-TYPE CLADDING LAYER 8 (μm)
A1	0.53	0.53	0.25
A2	0.55	0.55	0.25
A3	0.59	0.59	0.25
A4	0.70	0.70	0.25
A5	0.70	0.70	0.15

Fig. 2 shows that the maximum light output power obtained when fundamental transverse mode lasing is possible is not less than 100 mW when the real refractive index difference is not more than 3×10^{-3} , not less than 150 mW when the real refractive index difference is not more than 2.6×10^{-3} , and not less than 200 mW when the real refractive index difference is not more than 2.3×10^{-3} .

Additionally, a lasing threshold current of 43 mA, an operating current of 140 mA, a vertical beam divergence of

18°, and a horizontal beam divergence of 7° are obtained in the light output power of 100 mW when the real refractive index difference is not more than 3×10^{-3} , while a lasing threshold current of 45 mA, an operating current of 185 mA, a vertical beam divergence of 18°, and a horizontal beam divergence of 7° are obtained in the light output power of 170 mW when the real refractive index difference is not more than 2.5×10^{-3} .

When the real refractive index difference is not more than 2.3×10^{-3} , a lasing threshold current of 47 mA, an operating current of 235 mA, a vertical beam divergence of 18°, and a horizontal beam divergence of 6.5° are obtained in the light output power of 200 mW.

When the real refractive index difference is thus not more than 3×10^{-3} , high light output power is obtained at a low operating current in fundamental transverse mode lasing.

Consequently, in the semiconductor laser device according to the present embodiment, the real refractive index difference is set to not more than 3×10^{-3} and preferably not more than 2.6×10^{-3} .

The real refractive index difference Δn in a case where the semiconductor laser device is not operated (the real refractive index in the region a corresponding to the opening minus the real refractive index in the region b corresponding to both sides of the opening) is changed by selecting the respective Al composition ratios z_1 and z_2 of the current blocking layers 13 and 14, the thickness t of the p-type cladding layer 8, and the stripe width W , to measure maximum light output power P_k in fundamental transverse mode lasing. The results are shown in Table 2. In this case, a reflective film having an index of reflection of 2 % and a reflective film having an index of reflection of 95 % are respectively provided on a front facet and a rear facet of the semiconductor laser device, and the cavity length is set to 1200 μm , to make measurements at an ambient temperatures of 25 °C. Samples B4, B9, B14, B18, and B21 respectively correspond to the samples A1, A2, A3, A4, and A5.

Table 2

No.	Δn	W (μm)	P_k (mW)
B1	0.0023	5.5	110
B2	0.0023	5.1	150
B3	0.0023	4.7	180
B4	0.0023	4.5	200
B5	0.0025	6.0	90
B6	0.0025	5.4	95
B7	0.0025	5.0	120
B8	0.0025	4.8	150
B9	0.0025	4.5	170
B10	0.0025	4.2	200
B11	0.0030	5.7	80
B12	0.0030	5.3	85
B13	0.0030	4.9	90
B14	0.0030	4.5	100
B15	0.0030	4.3	120
B16	0.0038	5.3	55
B17	0.0038	4.9	60
B18	0.0038	4.5	60
B19	0.0050	5.5	45
B20	0.0050	4.9	45
B21	0.0050	4.5	50

Fig. 3 shows the relationship among the real refractive index difference Δn , the maximum light output power P_k obtained when fundamental transverse mode lasing is possible, and the stripe width W which are obtained using the samples Nos. B1 to B21 in the Table 1. Fundamental transverse mode lasing is obtained in all the samples B1 to B21.

Fig. 3 shows that the stripe width W and the real refractive index difference Δn which satisfy a region below a straight line L, including the straight line L must be selected in order that the maximum light output power P_k is not less than 100 mW, and the stripe width W and the real refractive index difference Δn which satisfy a region below a straight line M, including the straight line M must be selected in order that the maximum light output power P_k is not less than 150 mW.

The straight line L is represented by the following equation (A1):

$$W = -1.6 \times 10^3 \times \Delta n [\mu\text{m}] + 9.3 [\mu\text{m}] \quad (\text{A1})$$

The straight line M is represented by the following equation (A2):

$$W = -1.5 \times 10^3 \times \Delta n [\mu\text{m}] + 8.55 [\mu\text{m}] \quad (\text{A2})$$

In the semiconductor laser device, the substantial real refractive index in the region a is decreased by approximately 10^{-3} upon injection of carriers into the region a when the semiconductor laser device is operated. Therefore, it is preferable that the real refractive index difference is not less than 2×10^{-3} in order to keep a real refractive index guided structure good.

Particularly, it is preferable that the stripe width W is not less than $3.0 \mu\text{m}$ in terms of reliability. Specifically, it is preferable that the stripe width W is not less than $3.0 \mu\text{m}$ in order that the semiconductor laser device stably operates for not less than 1000 hours.

From the foregoing, the stripe width W and the real refractive index difference Δn are so selected as to satisfy the following relationships in order that the maximum light output power P_k is not less than 100 mW in fundamental transverse mode lasing:

$$\Delta n \geq 2 \times 10^{-3}$$

$$W \leq -1.6 \times 10^3 [\mu\text{m}] \times \Delta n + 9.3 [\mu\text{m}]$$

$$W \geq 3.0 [\mu\text{m}]$$

It is more preferable that the following relationship is satisfied in addition to the foregoing relationships in order that the maximum light output power P_k is not less than 150 mW in fundamental transverse mode lasing:

$$W \leq -1.5 \times 10^3 [\mu\text{m}] \times \Delta n + 8.55 [\mu\text{m}]$$

A current blocking layer having a large band gap (having a high Al composition ratio) is relatively inferior in crystallinity. As a result, impurities may be diffused into the active layer 6 from the current blocking layer in growing the current blocking layer again. Moreover, the thickness of the p-type cladding layer 8 is set to a small value and preferably not more than $0.25 \mu\text{m}$ in order that the semiconductor laser device is formed into a real refractive index guided semiconductor laser device to reduce an unavailing current. In order to prevent the above-mentioned dispersion, therefore, the current blocking layer 13 on the side of the active layer 6 is preferably formed into a low impurity layer such as an undoped layer as in the present embodiment, and more preferably formed into an undoped layer as described above.

Although in the above-mentioned first embodiment, a single quantum well structure layer composed of $\text{Al}_q\text{Ga}_{1-q}\text{As}$ ($q \geq 0$) is used as the active layer 6, a multi quantum well structure layer composed of $\text{Al}_q\text{Ga}_{1-q}\text{As}$ well layers and $\text{Al}_p\text{Ga}_{1-p}\text{As}$ barrier layers ($p > q \geq 0$) may be used as the active layer 6. Alternatively, a layer having no quantum effect composed of $\text{Al}_q\text{Ga}_{1-q}\text{As}$ ($q \geq 0$) may be used as the active layer 6.

An AlGaAs system semiconductor laser device according to a second embodiment of the present invention will be described using Figs. 4 and 5. In the semiconductor laser device shown in Fig. 4, portions corresponding to those in the semiconductor laser device shown in Fig. 1 are assigned the same reference numerals.

In Fig. 4, an Se doped n-type GaAs buffer layer 2 having a thickness of $0.5 \mu\text{m}$, an Se doped n-type $\text{Al}_s\text{Ga}_{1-s}\text{As}$ buffer layer 3 having a thickness of $0.1 \mu\text{m}$, and an Se doped $\text{Al}_x\text{Ga}_{1-x}\text{As}$ cladding layer 4 having a thickness of 2.2

μm are formed in this order on an n-type GaAs substrate 1, where $x > s > 0$. In the present embodiment, $s = 0.18$ and $x = 0.45$.

An undoped $\text{Al}_v\text{Ga}_{1-v}\text{As}$ optical guide layer 5 having a thickness of 200 \AA , an undoped active layer 6, and an undoped $\text{Al}_w\text{Ga}_{1-w}\text{As}$ optical guide layer 7 having a thickness of 200 \AA are formed in this order on the n-type cladding layer 4, where $1 > x > v$. In the present embodiment, $v = 0.35$. The active layer 6 is constructed by alternately stacking quantum well layers 6a composed of $\text{Al}_q\text{Ga}_{1-q}\text{As}$ having a thickness of 80 \AA and barrier layers 6b composed of $\text{Al}_p\text{Ga}_{1-p}\text{As}$ having a thickness of 80 \AA . Here $v \geq p > q \geq 0$ and $w \geq p > q \geq 0$. In the present embodiment, $q = 0.11$ and $p = 0.3$. Further, $y_1 > w$ and $y_2 > w$. In the present embodiment, $w = 0.35$.

A Zn doped p-type $\text{Al}_{y_1}\text{Ga}_{1-y_1}\text{As}$ cladding layer 8 having a thickness of $t \mu\text{m}$ is formed on the optical guide layer 7. In the present embodiment, $y_1 = 0.45$.

A stripe-shaped Zn doped p-type $\text{Al}_u\text{Ga}_{1-u}\text{As}$ etching stop layer 9 having a thickness of 200 \AA extending in the vertical direction (in the direction of the cavity length), a stripe-shaped Zn doped p-type $\text{Al}_{y_2}\text{Ga}_{1-y_2}\text{As}$ cladding layer 10 having a thickness of $1.8 \mu\text{m}$, and a stripe-shaped Zn doped p-type GaAs cap layer 11 having a thickness of $0.7 \mu\text{m}$ are formed in this order on an approximately central part of the p-type cladding layer 8. The p-type etching stop layer 9 has a width of $W \mu\text{m}$. The width $W \mu\text{m}$ becomes the width of an opening forming a current path. Here $1 \geq u > y_1$ and $1 \geq u > y_2$. In the present embodiment, $u = 0.7$ and $y_2 = 0.45$. The p-type etching stop layer 9, the p-type cladding layer 10, and p-type cap layer 11 constitute a stripe-shaped ridge portion 12.

An undoped $\text{Al}_{z_1}\text{Ga}_{1-z_1}\text{As}$ current blocking layer 13 having a thickness of $0.3 \mu\text{m}$, an Se doped n-type $\text{Al}_{z_2}\text{Ga}_{1-z_2}\text{As}$ current blocking layer 14 having a thickness of $0.2 \mu\text{m}$, and an Se doped n-type GaAs current blocking layer 15 having a thickness of $0.3 \mu\text{m}$ are formed in this order on the p-type cladding layer 8 so as to cover the side surface of the ridge portion 12, where $1 \geq z_1 > y_1$, $1 \geq z_1 > y_2$, $1 \geq z_2 > y_1$, and $1 \geq z_2 > y_2$.

A Zn doped p-type GaAs contact layer 16 having a thickness of $6 \mu\text{m}$ is formed on the upper surface of the p-type cap layer 11, the end surface of the undoped current blocking layer 13, the end surface of the n-type current blocking layer 14, and the upper surface and the end surface of the n-type current blocking layer 15.

A p-side electrode 17 composed of Cr/Au is formed on the p-type contact layer 16, and an n-side electrode 18 composed of Cr/Sn/Au is formed on the lower surface of the n-type substrate 1.

A method of fabricating the semiconductor laser device shown in Fig. 4 is the same as the method of fabricating the semiconductor laser device shown in Fig. 1 except for the detailed structure of the active layer 6.

In the semiconductor laser device, the current blocking layers 13 and 14 having a stripe-shaped opening (a stripe width W) for restricting a current path as well as forming the current path have larger band gaps and smaller refractive indexes than those of the p-type cladding layers 8 and 10. Consequently, in a light emitting region (a region schematically indicated by an ellipse of a dotted line in Fig. 4), a real refractive index in a region a corresponding to the opening can be made larger than a real refractive index in a region b corresponding to both sides of the opening. Consequently, the semiconductor laser device is operable as a real refractive index guided semiconductor laser device.

By the above-mentioned construction, the current blocking layers 13 and 14 become transparent current blocking layers which are transparent to lasing light.

A real refractive index difference Δn in a case where the semiconductor laser device is not operated (a real refractive index n_0 in the region a corresponding to the opening minus a real refractive index n_s in the region b corresponding to both sides of the opening) is changed by selecting the respective Al composition ratios z_1 and z_2 of the current blocking layers 13 and 14, the thickness t of the p-type cladding layer 8, and the stripe width, to measure maximum light output power P_k obtained when fundamental transverse mode lasing is possible, a horizontal beam divergence θ_H in the horizontal direction at that time, COD (catastrophic optical damage), and astigmatism. The results are shown in Table 3. In this case, a reflective film having an index of reflection of 12 % and a reflective film having an index of reflection of 95 % are respectively provided on a front facet and a rear facet of the semiconductor laser device, and the cavity length is set to $600 \mu\text{m}$, to make measurements at an ambient temperature of 25°C .

Table 3

No.	t (μm)	Al COMPOSITION RATIO Z1=Z2	Δn	W (μm)	Fundamental TRANSVERS- MODE LASING	θ ANGLE	Pk (mW)	COD (mW)	ASTIGMATISM (μm)
C1	0.25	0.52	0.0020	4.5	○	5.6	115	190	35
C2	0.23	0.52	0.0024	4.8	○	5.6	95	175	9
C3	0.23	0.52	0.0024	4.0	○	5.5	120	180	7
C4	0.23	0.52	0.0024	3.2	○	5.9	145	185	7
C5	0.22	0.57	0.0028	5.0	○	5.6	70	200	8
C6	0.22	0.57	0.0028	4.3	○	6.0	100	185	6
C7	0.22	0.57	0.0028	3.5	○	6.5	110	180	5
C8	0.22	0.57	0.0028	3.2	○	7.0	120	150	5
C9	0.21	0.57	0.0031	4.6	○	6.1	70	180	7
C10	0.21	0.57	0.0031	3.8	○	7.0	100	170	5
C11	0.21	0.57	0.0031	3.3	○	7.2	110	150	4
C12	0.21	0.57	0.0031	2.8	○	7.6	110	140	5
C13	0.21	0.57	0.0031	2.5	○	7.8	100	100	4
C14	0.21	0.57	0.0031	2.0	○	8.1	50	50	3
C15	0.20	0.52	0.0033	4.5	○	6.7	60	180	7
C16	0.20	0.52	0.0033	3.6	○	7.4	95	160	7
C17	0.20	0.52	0.0033	3.2	○	7.5	115	150	4
C18	0.19	0.57	0.0035	4.6	○	7.1	50	175	6
C19	0.17	0.57	0.0040	4.0	×	4.6	0	140	-
C20	0.15	0.57	0.0045	4.0	×	4.2	0	150	-

Fig. 6 shows the relationship among the real refractive index difference Δn , the maximum light output power P_k obtained when fundamental transverse mode lasing is possible, the stripe width W , and the horizontal beam divergence θ_H which are obtained using samples Nos. C1 to C18 in the Table 3.

Fig. 6 shows that the stripe width W and the real refractive index difference Δn which satisfy a region RA between a straight line A indicated by a dotted line and a straight line X indicated by a dotted line must be selected in order that the maximum light output power P_k is not less than 70 mW, and the stripe width W and the real refractive index difference Δn which satisfy a region RB between a straight line B indicated by a dotted line and the above-mentioned straight line X must be selected in order that the maximum light output power P_k is not less than 100 mW.

Furthermore, Fig. 6 shows that the stripe width W and the real refractive index difference Δn which satisfy a region RC below a straight line C indicated by a solid line, including the straight line C must be selected in order that the horizontal beam divergence θ_H is not less than 6.5° , and the stripe width W and the real refractive index difference Δn which satisfy a region RD below a straight line D indicated by a solid line, including the straight line D must be selected in order that the horizontal beam divergence θ_H is not less than 7° .

The straight line A is represented by the following equation (B1):

$$W = -1.33 \times 10^3 [\mu\text{m}] \times \Delta n + 8.723 [\mu\text{m}] \quad (\text{B1})$$

The straight line B is represented by the following equation (B2):

$$W = -1.33 \times 10^3 [\mu\text{m}] \times \Delta n + 7.923 [\mu\text{m}] \quad (\text{B2})$$

The straight line X is represented by the following equation (B3):

$$W = 2.5 [\mu\text{m}] \quad (\text{B3})$$

The straight line C is represented by the following equation (B4):

$$W = 2.25 \times 10^3 [\mu\text{m}] \times \Delta n - 2.8 [\mu\text{m}] \quad (\text{B4})$$

The straight line D is represented by the following ; equation (B5):

$$W = 2.25 \times 10^3 [\mu\text{m}] \times \Delta n - 3.175 [\mu\text{m}] \quad (\text{B5})$$

Fig. 7 shows the relationship between the COD and the stripe width W in the samples Nos. C9 to C14 shown in the foregoing Table 3.

As can be seen from Fig. 7 and the Table 3, when the stripe width W is less than $2.5 \mu\text{m}$, the COD is less than 100 mW, except that the maximum light output power P_k is less than 100 mW, whereby the life of the semiconductor laser device cannot be lengthened.

Fig. 8 shows the relationship between the astigmatism and the real refractive index difference Δn in the samples Nos. C1, C2, C5, C9, and C18 shown in the foregoing Table 3.

As can be seen from Fig. 8 and the Table 3, when the real refractive index difference Δn is less than 2.4×10^{-3} , the astigmatism is rapidly increased. When the astigmatism is thus very large, optical setting in an optical pickup, for example, becomes difficult. Therefore, it is preferable that the real refractive index difference Δn is not less than 2.4×10^{-3} .

Furthermore, when the real refractive index difference Δn exceeds 3.5×10^{-3} , transverse mode lasing becomes unstable, and fundamental transverse mode lasing becomes difficult, as shown in the Table 3. Consequently, it is preferable that the real refractive index difference Δn is not less than 2.4×10^{-3} nor more than 3.5×10^{-3} .

It is desired that the maximum light output power P_k is not less than 70 mW and the horizontal beam divergence θ_H is not less than 6.5° in a semiconductor laser device serving as a light source for a rewritable optical disc. In the present invention, therefore, the stripe width W and the real refractive index difference Δn are so selected as to satisfy an area where the region RA and the region RC are overlapped with each other and a range in which the real refractive index difference Δn is not less than 2.4×10^{-3} nor more than 3.5×10^{-3} .

That is, the stripe width W and the real refractive index difference Δn satisfy the following equations:

$$2.4 \times 10^{-3} \leq \Delta n \leq 3.5 \times 10^{-3}$$

$$W \leq -1.33 \times 10^3 [\mu\text{m}] \times \Delta n + 8.723 [\mu\text{m}]$$

$$W \leq 2.25 \times 10^3 [\mu\text{m}] \times \Delta n - 2.8 [\mu\text{m}]$$

$$W \geq 2.5 [\mu\text{m}]$$

It is preferable that the following relationship is satisfied in addition to the foregoing relationships in order that the maximum light output power P_k is not less than 100 mW:

$$W \leq -1.33 \times 10^3 [\mu\text{m}] \times \Delta n + 7.923 [\mu\text{m}]$$

It is more preferable that the following relationship is satisfied in order that the horizontal beam divergence θ_H is not less than 7° :

$$W \leq 2.25 \times 10^3 [\mu\text{m}] \times \Delta n - 3.175 [\mu\text{m}]$$

It is still more preferable that the following relationships are satisfied in order that the maximum light output power P_k is not less than 100 mW, and the horizontal beam divergence θ_H is not less than 7° :

$$2.4 \times 10^{-3} \leq \Delta n \leq 3.5 \times 10^{-3}$$

$$W \geq 2.5 [\mu\text{m}]$$

$$W \leq 1.33 \times 10^3 [\mu\text{m}] \times \Delta n - 0.323 [\mu\text{m}]$$

$$W \leq 2.25 \times 10^3 [\mu\text{m}] \times \Delta n - 3.175 [\mu\text{m}]$$

Furthermore, a current blocking layer having a large band gap (having a high Al composition ratio) is relatively inferior in crystallinity. As a result, impurities may be diffused into the active layer 6 from the current blocking layer in growing the current blocking layer again. Moreover, the thickness of the p-type cladding layer 8 is set to a small value and preferably not more than $0.25 \mu\text{m}$ in order that the semiconductor laser device is formed into a real refractive index guided semiconductor laser device to reduce an unavailing current. In order to prevent the above-mentioned dispersion, therefore, the current blocking layer 13 on the side of the active layer 6 is preferably formed into a low impurity layer such as an undoped layer as in the present embodiment, and more preferably formed into an undoped layer as described above.

Although in the above-mentioned second embodiment, a multi quantum well structure layer composed of $\text{Al}_q\text{Ga}_{1-q}\text{As}$ quantum well layers and $\text{Al}_p\text{Ga}_{1-p}\text{As}$ barrier layers ($P > q \geq 0$) is used as the active layer 6, a single quantum well layer composed of $\text{Al}_q\text{Ga}_{1-q}\text{As}$ ($q \geq 0$) may be used. Alternatively, a layer having no quantum effect composed of $\text{Al}_q\text{Ga}_{1-q}\text{As}$ ($q \geq 0$) may be used.

Although in the above-mentioned first and second embodiments, the etching stop layer 9 exists between the p-type cladding layers 8 and 10, that is, in the p-type cladding layer, the etching stop layer 9 need not be provided, provided that the decrease in yield is allowed.

In the above-mentioned first and second embodiments, the respective Al composition ratios x , y_1 , and y_2 of the AlGaAs cladding layers 4, 8, and 10 can be suitably selected in the range of not less than 0.4 nor more than 0.6, the

respective Al composition ratios z_1 and z_2 of the current blocking layers 13 and 14, which are higher than the respective Al composition ratios y_1 and y_2 of the AlGaAs cladding layers 8 and 10, having a stripe-shaped opening having a predetermined width for restricting a current path as well as forming the current path and adjacent to each other are set to be more than the respective Al composition ratios y_1 and y_2 of the AlGaAs cladding layers 8 and 10 by at least 0.02.

However, it is confirmed by experiments that when AlGaAs is inferior in crystallinity and is easily oxidized when the Al composition ratio thereof is more than 0.6, so that crystal growth thereon becomes difficult. Therefore, it is preferable that the respective Al composition ratios z_1 and z_2 of the current blocking layers 13 and 14 are set to not more than 0.6.

Furthermore, although in the above-mentioned first and second embodiments, the n-type AlGaAs current blocking layer 14 and the undoped current blocking layer 13 have the same Al composition ratio, the current blocking layer 14 and the current blocking layer 13 may have different Al composition ratios. Further, the semiconductor laser device may comprise only one of the current blocking layers 13 and 14.

Although the present invention has been described and illustrated in detail, it is clearly understood that the same is by way of illustration and example only and is not to be taken by way of limitation.

Claims

1. A semiconductor laser device comprising in the order listed:

a cladding layer of a first conductivity type;

an active layer;

a cladding layer of a second conductivity type; and

a current blocking layer having a stripe-shaped opening of a predetermined width for restricting a current path and forming the current path, and having a larger band gap than that of said cladding layer of the second conductivity type and having a smaller refractive index than that of said cladding layer of the second conductivity type,

said cladding layer of the second conductivity type having a flat portion and a stripe-shaped ridge portion on said flat portion,

said ridge portion being positioned in said opening of said current blocking layer,

said current blocking layer being so formed as to cover the upper surface of said flat portion and the side surface of said ridge portion, and

a difference Δn between a real refractive index in a region, which corresponds to said opening, in said active layer and a real refractive index in a region, which corresponds to both sides of said opening, in said active layer and the width W [μm] of said opening satisfying the following relationship:

$$\Delta n \geq 2 \times 10^{-3},$$

$$W \leq -1.6 \times 10^3 \times \Delta n + 9.3,$$

and

$$W \geq 3.0$$

2. The semiconductor laser device according to claim 1, wherein

the difference Δn between the real refractive indexes and the width W of said opening satisfy the following relationship:

$$W \leq -1.5 \times 10^3 \times \Delta n + 8.55$$

3. The semiconductor laser device according to claim 1, wherein

said cladding layer of the first conductivity type is composed of $\text{Al}_x\text{Ga}_{1-x}\text{As}$, said active layer is composed of $\text{Al}_q\text{Ga}_{1-q}\text{As}$ ($1 > x > q \geq 0$), said cladding layer of the second conductivity type is composed of $\text{Al}_y\text{Ga}_{1-y}\text{As}$ ($y > q$),

and said current blocking layer is composed of $\text{Al}_z\text{Ga}_{1-z}\text{As}$.

4. The semiconductor laser device according to claim 1, wherein

said current blocking layer comprises an Al,
the difference Δn between the real refractive indexes is set by selecting the Al composition ratio of said current blocking layer and the thickness of said cladding layer of the second conductivity type on the both sides of the opening.

5. The semiconductor laser device according to claim 4, wherein

the Al composition ratio z of said current blocking layer is higher than the Al composition ratio y of said cladding layer of the second conductivity type.

6. The semiconductor laser device according to claim 4, wherein

the Al composition ratio z of said current blocking layer is not more than 0.6.

7. The semiconductor laser device according to claim 1, wherein

the width of said ridge portion at a distance away from said active layer decreases as the distance increases.

8. The semiconductor laser device according to claim 1, wherein

said current blocking layer comprises at least a layer of said first conductivity type.

9. The semiconductor laser device according to claim 1, wherein

said current blocking layer comprises a first layer formed on said active layer and a second layer formed on said first layer,
said second layer being of said first conductivity type,
said first layer having a lower impurity concentration than that of said second layer.

10. A method of designing a semiconductor laser device comprising a cladding layer of a first conductivity type composed of $\text{Al}_x\text{Ga}_{1-x}\text{As}$, an active layer composed of $\text{Al}_q\text{Ga}_{1-q}\text{As}$ ($1 > x > q \geq 0$), a cladding layer of a second conductivity type composed of $\text{Al}_y\text{Ga}_{1-y}\text{As}$ ($y > q$), and a current blocking layer having a stripe-shaped opening having a predetermined width for restricting a current path and forming the current path and composed of $\text{Al}_z\text{Ga}_{1-z}\text{As}$ ($1 \geq z > y$) in this order, comprising the steps of:

setting a difference Δn between a real refractive index in a region, which corresponds to said opening, in said active layer and a real refractive index in a region, which corresponds to both sides of said opening, in said active layer and the width W of said opening in order that predetermined light output power is obtained in fundamental transverse mode lasing; and

selecting the Al composition ratio z of said current blocking layer and the thickness of said cladding layer of the second conductivity type on the both sides of the opening in order that said difference Δn between the real refractive indexes is obtained.

11. The method according to claim 10, wherein

said setting step comprises the step of setting said difference Δn between the real refractive indexes and the width W [μm] of said opening in order to satisfy the following relationships:

$$\Delta n \geq 2 \times 10^{-3},$$

and

$$W \leq -1.6 \times 10^3 \times \Delta n + 9.3$$

12. The method according to claim 11, wherein

said setting step comprises the step of setting said difference Δn between the real refractive indexes and the width W [μm] of said opening in order to satisfy the following relationship:

$$W \leq -1.5 \times 10^3 \times \Delta n + 8.55$$

13. The method according to claim 11, wherein

said setting step comprises the step of setting the width W of said opening to not less than 3.0 μm .

14. The method according to claim 10, wherein

said cladding layer of the second conductivity type comprises a flat portion and a stripe-shaped ridge portion on said flat portion,
said ridge portion being positioned in said opening of said current blocking layer,
said current blocking layer being so formed as to cover the upper surface of said flat portion and the side surface of said ridge portion.

15. The method according to claim 14, wherein

the width of said ridge portion at a distance away from said active layer decreases as the distance increases.

16. A semiconductor laser device comprising in the order listed:

a cladding layer of a first conductivity type;
an active layer;
a cladding layer of a second conductivity type; and
a current blocking layer having a stripe-shaped opening of a predetermined width for restricting a current path and forming the current path, and having a larger band gap than that of said cladding layer of the second conductivity type and having a smaller refractive index than that of said cladding layer of the second conductivity type,
said cladding layer of the second conductivity type having a flat portion and a stripe-shaped ridge portion on said flat portion,
said ridge portion being positioned in said opening of said current blocking layer,
said current blocking layer being so formed as to cover the upper surface of said flat portion and the side surface of said ridge portion,
a difference Δn between a real refractive index in a region, which corresponds to said opening, in said active layer and a real refractive index in a region, which corresponds to both sides of said opening, in said active layer and the width W [μm] of said opening satisfying the following relationships:

$$2.4 \times 10^{-3} \leq \Delta n \leq 3.5 \times 10^{-3},$$

$$W \geq 2.5,$$

$$W \leq -1.33 \times 10^3 \times \Delta n + 8.723,$$

and

$$W \leq 2.25 \times 10^3 \times \Delta n - 2.8$$

17. The semiconductor laser device according to claim 16, wherein

said difference Δn between the real refractive indexes and the width W [μm] of said opening satisfy the following relationship:

$$W \leq -1.33 \times 10^3 \times \Delta n + 7.923$$

18. The semiconductor laser device according to claim 16, wherein

the difference Δn between the real refractive indexes and the width W [μm] of said opening satisfy the

following relationship:

$$W \leq 2.25 \times 10^3 \times \Delta n - 3.175.$$

19. The semiconductor laser device according to claim 16, wherein

said current blocking layer comprises an Al,
the difference Δn between the real refractive indexes is set by selecting the Al composition ratio of said current blocking layer and the thickness of said cladding layer of the second conductivity type on the both sides of the opening.

20. The semiconductor laser device according to claim 16, wherein

said cladding layer of the first conductivity type is composed of $\text{Al}_x\text{Ga}_{1-x}\text{As}$, said active layer is composed of $\text{Al}_q\text{Ga}_{1-q}\text{As}$ ($1 > x > q \geq 0$), said cladding layer of the second conductivity type is composed of $\text{Al}_y\text{Ga}_{1-y}\text{As}$ ($y > q$), and said current blocking layer is composed of $\text{Al}_z\text{Ga}_{1-z}\text{As}$.

21. The semiconductor laser device according to claim 20, wherein

the Al composition ratio z of said current blocking layer is higher than the Al composition ratio y of said cladding layer of the second conductivity type.

22. The semiconductor laser device according to claim 20, wherein

the Al composition ratio z of said current blocking layer is not more than 0.6.

23. The semiconductor laser device according to claim 16, wherein

the width of said ridge portion at a distance away from said active layer decreases as the distance increases.

24. The semiconductor laser device according to claim 16, wherein

said current blocking layer comprises at least a layer of said first conductivity type.

25. The semiconductor laser device according to claim 16, wherein

said current blocking layer comprises a first layer formed on said active layer and a second layer formed on said first layer,
said second layer being of said first conductivity type, said first layer having a lower impurity concentration than that of said second layer.

26. A method of designing a semiconductor laser device comprising a cladding layer of a first conductivity type composed of $\text{Al}_x\text{Ga}_{1-x}\text{As}$, an active layer composed of $\text{Al}_q\text{Ga}_{1-q}\text{As}$ ($1 > x > q \geq 0$), a cladding layer of a second conductivity type composed of $\text{Al}_y\text{Ga}_{1-y}\text{As}$ ($y > q$), and a current blocking layer having a stripe-shaped opening having a predetermined width for restricting a current path and forming the current path and composed of $\text{Al}_z\text{Ga}_{1-z}\text{As}$ ($1 \geq z > y$) in this order, comprising the steps of:

setting a difference Δn between a real refractive index in a region, which corresponds to said opening, in said active layer and a real refractive index in a region, which corresponds to both sides of said opening, in said active layer and the width W of said opening in order that predetermined maximum light output power and a predetermined horizontal beam divergence are obtained in fundamental transverse mode lasing; and selecting the Al composition ratio z of said current blocking layer and the thickness of said cladding layer of the second conductivity type on the both sides of the opening in order that said difference Δn between the real refractive indexes is obtained.

27. The method according to claim 26, wherein

said setting step comprises the step of setting said difference Δn between the real refractive indexes and the width W [μm] of said opening in order to satisfy the following relationships:

$$2.4 \times 10^{-3} \leq \Delta n \leq 3.5 \times 10^{-3},$$

$$W \geq 2.5,$$

$$W \leq -1.33 \times 10^3 \times \Delta n + 8.723,$$

and

$$W \leq 2.25 \times 10^3 \times \Delta n - 2.8$$

28. The method according to claim 27, wherein

said setting step comprises the step of setting said difference Δn between the real refractive indexes and the width W [μm] of said opening in order to satisfy the following relationship:

$$W \leq -1.33 \times 10^3 \times \Delta n + 7.923$$

29. The method according to claim 27, wherein

said setting step comprises the step of setting said difference Δn between the real refractive indexes and the width W [μm] of said opening in order to satisfy the following relationship:

$$W \leq 2.25 \times 10^3 \times \Delta n - 3.175$$

30. The method according to claim 26, wherein

said cladding layer of the second conductivity type comprises a flat portion and a stripe-shaped ridge portion on said flat portion,

said ridge portion being positioned in said opening of said current blocking layer,

said current blocking layer being so formed as to cover the upper surface of said flat portion and the side surface of said ridge portion.

31. The method according to claim 30, wherein

the width of said ridge portion at a distance away from said active layer decreases as the distance increases.

FIG. 1

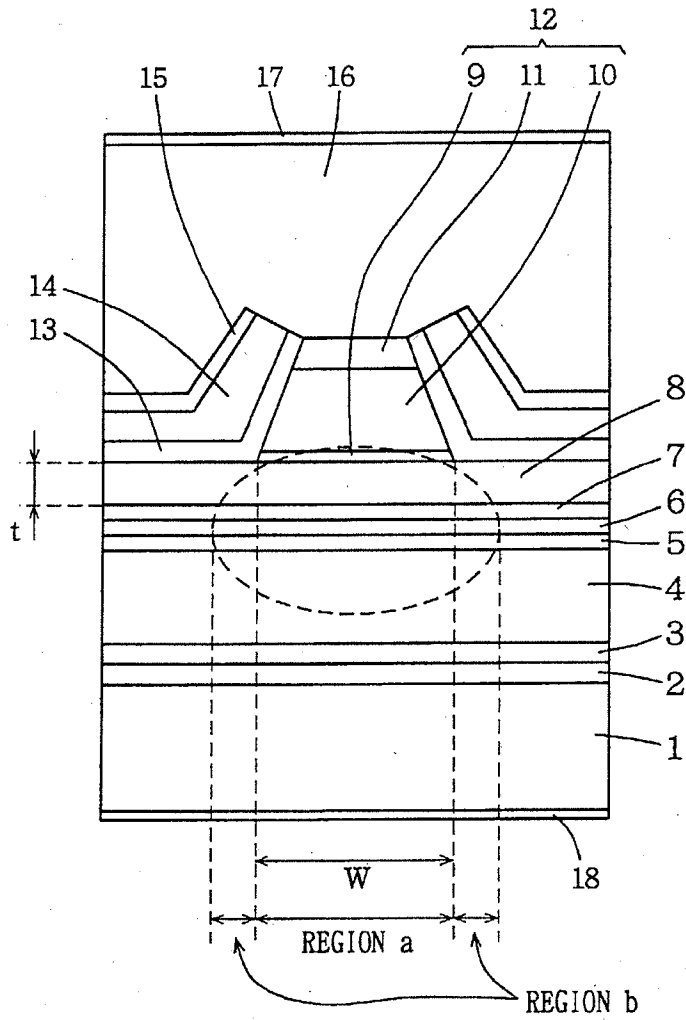


FIG. 2

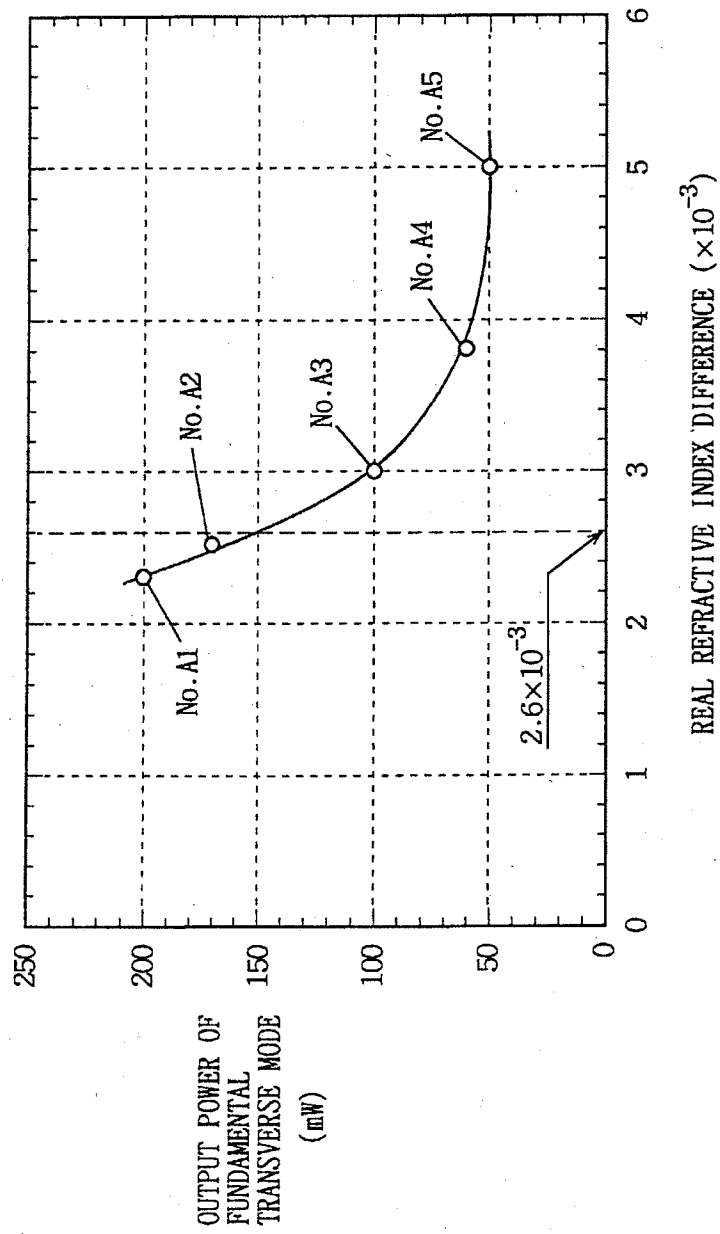


FIG. 3

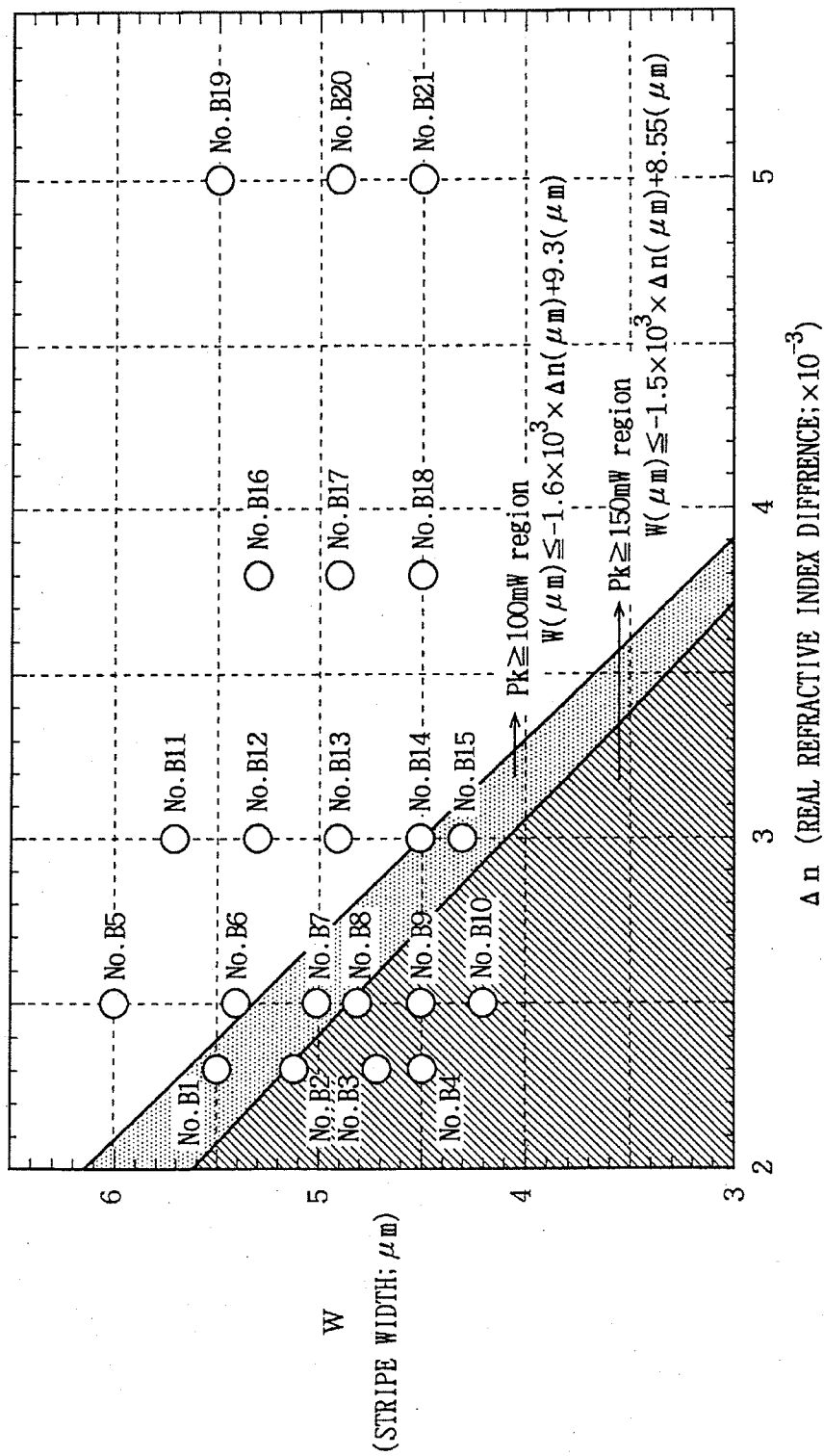


FIG. 4

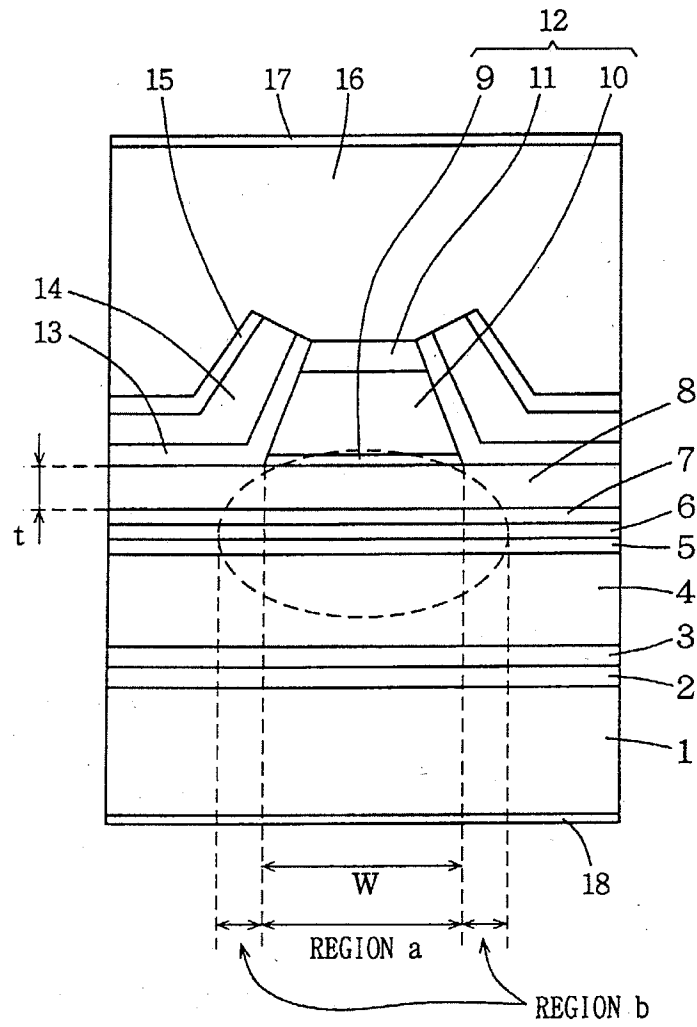


FIG. 5

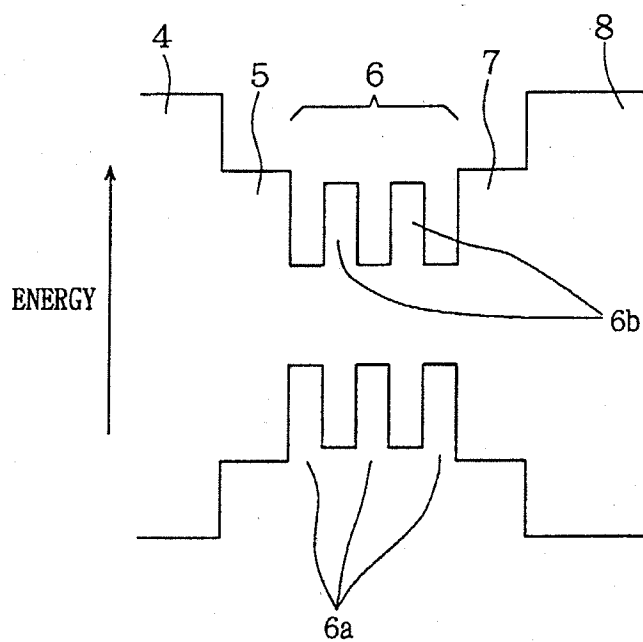


FIG. 6

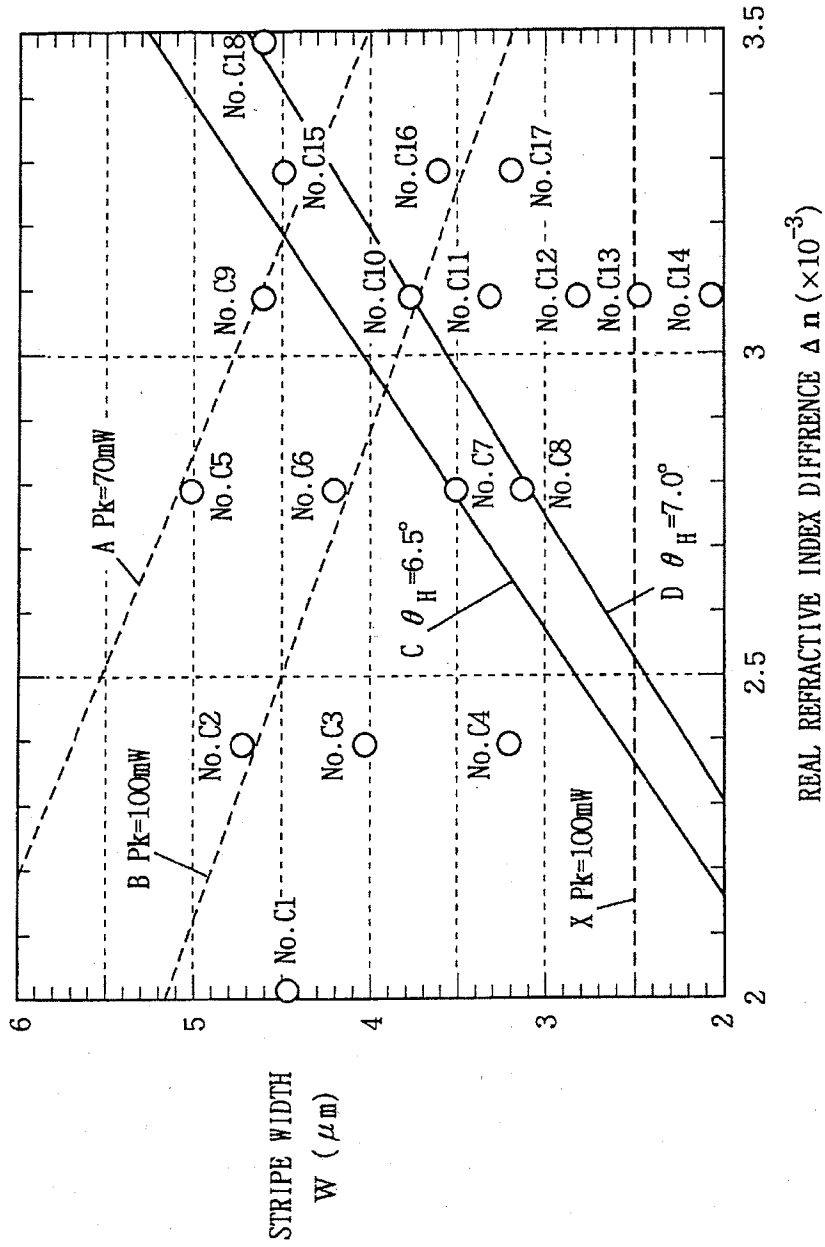


FIG. 7

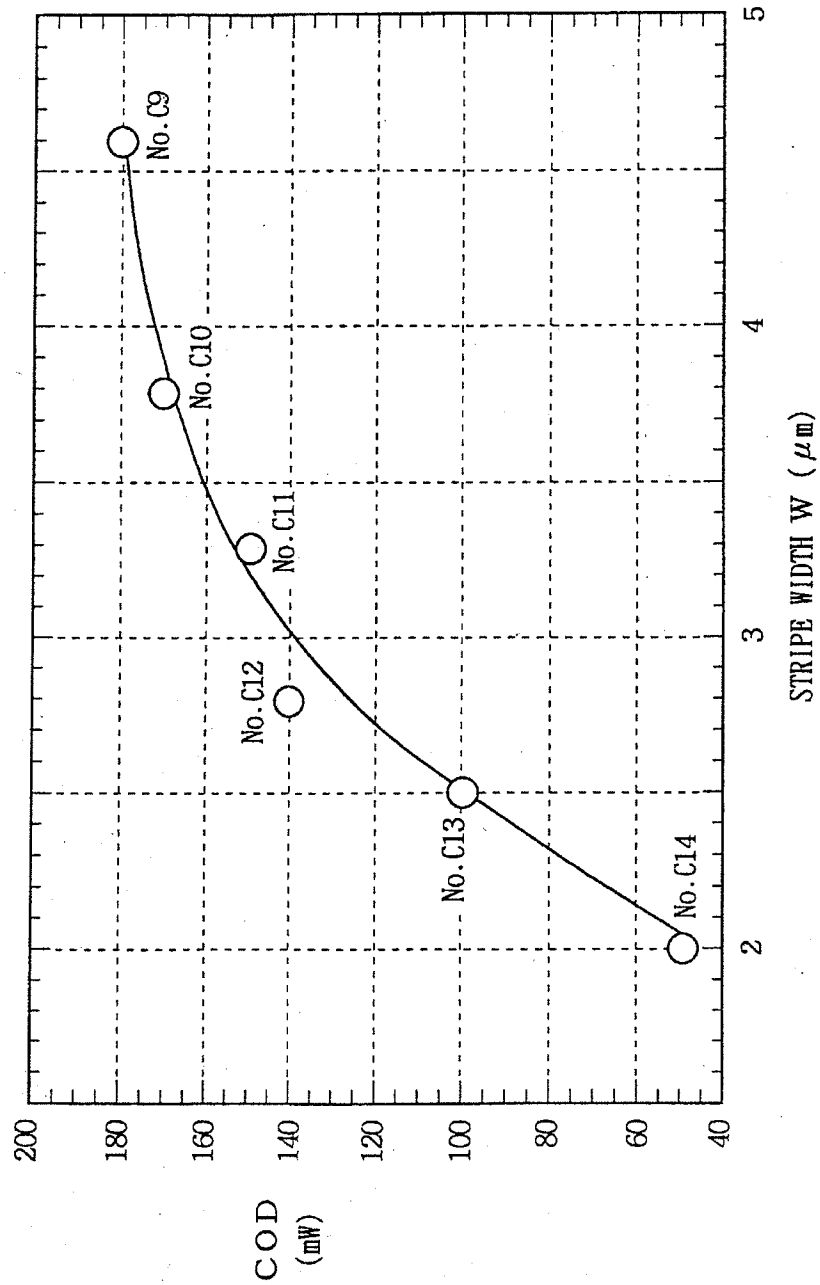


FIG. 8

